THE IMPLICATIONS AND RISKS OF AN AGILE MANUFACTURING INDUSTRIAL BASE TO U.S. ARMY MATÉRIEL READINESS FOR RAPID REACTION MAJOR REGIONAL CONFLICTS

by

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DISCLAIMER NOTICE

To my family, the single focal point that--more than anything else in my existence during the past three years--not only has made this endeavor possible through their collective self-sacrifice and support, but kept bringing me back to reality with tangible, gentle reminders of those things that are really important in life.

This work is dedicated to each of you,

Nancy

Jennifer

David

&

Grace,

with all my love.

ABSTRACT

JONES, KENNETH LEE. The Implications and Risks of an Agile Manufacturing Industrial Base to U.S. Army Matériel Readiness for Rapid Reaction Major Regional Conflicts. (Under the direction of Dr. Thom J. Hodgson and Dr. Russell E. King.)

The evolution of "agile manufacturing" techniques and practices in the industrial base of the United States and the victory of capitalism over communism in the Cold War have far-reaching economic, political, and social implications for the coming decade. Agile manufacturing promises high-quality, individually customized, price-competitive products produced on demand. Post–Cold War budget reductions will cause many major weapons systems in the U.S. Army inventory to be used at least through the next decade, long after production has ended. The synergy of agile manufacturing expectations and the rapid dismemberment of the defense industrial base as weapons systems go out of production represents a subtle but potentially dangerous threat to the Class IX repair part matériel readiness of U.S. Army weapons systems in projected major regional contingencies. A stochastic simulation methodology is presented which enables: (1) parametric estimation of the daily repair part requirements for all repair parts for a particular major weapons system in two nearly simultaneous regional conflict scenarios; and (2) comparison of alternative policies of inventory and industrial capacity in accommodating repair part requirements. Business as usual will lead to severe shortfalls of critical repair parts rendering major weapons systems unavailable during contingencies and potentially cause entire battalions to become ineffective.

For the want of a nail the shoe was lost,
For the want of a shoe the horse was lost,
For the want of a horse the rider was lost,
For the want of a rider the battle was lost,
For the want of a battle the kingdom was lost--
And all for want of a horseshoe-nail.

--Benjamin Franklin, 1758

Biography

Born September 6, 1955, in New Boston, Texas, Kenneth L. Jones grew up in the relative calm and safety of small town America. He attended the United States Military Academy, West Point, New York, as a member of the Class of 1978 and was commissioned a Second Lieutenant in the United States Army Corps of Engineers on June 7, 1978. The next five years were spent in combat engineer assignments in the former West Germany. There he met his wife, the former Nancy Garrett Kline, a United States Army Ordnance Corps officer. They were married in Bern, Switzerland and enjoyed extensive travel in Germany, Italy, the United Kingdom, Austria, Switzerland, and Greece as well as visits to the former Soviet Union and Yugoslavia. Returning to the United States in 1984, he became an industrial engineer by necessity when tasked to manage the transition of over 2,000 people at Red River Army Depot, Texas, from 1942 vintage repair facilities for the United States Army's M113 Family of Armored Personnel Carriers into a newly constructed, highly automated facility while simultaneously integrating overhaul and repair capability for the Bradley Fighting Vehicle into the production schedule. Receiving a Master of Science degree in Aerospace Engineering from the University of Texas at Austin in 1989 and the serendipitous creation of the Army Acquisition Corps by the Congress led him to research and development assignments in two major United States Army weapons systems program management offices in Huntsville, Alabama. He continues his military career at the United States Army Research Office, Research Triangle Park, North Carolina and resides in Cary, North Carolina, with his wife and three children.

Acknowledgements

The author wishes to recognize the myriad people who were instrumental in facilitating this research. First, I must thank Dr. Thom Hodgson for suggesting that I investigate the emerging literature concerning agile manufacturing. The promise and demonstrated potential of agile manufacturing led me to choose this area of research. Dr. Edward Kaitz's probing questions and advice were the catalysts that led me to focus my research. The reams of data that were distilled to produce the anticipated daily combat status of the tank battalions assigned to the Southwest Asia and Northeast Asia major regional contingencies could not have been processed without the support of Dr. Gerald Klopp and the programming talents of Mr. William Palmer at Fort Lee, VA. Mr. Henry Simberg and Ms. Vicki Evering of the Army Matériel Systems Analysis Activity at Aberdeen Proving Ground, MD, researched and provided repair part failure factor data for the critical repair parts on the Abrams Main Battle Tank. LTC Mike Cannon and Mr. Lieu Lipecke provided guidance and insights from the Abrams Program Management Office in Warren, MI.

Others to whom I owe a debt of gratitude include: Mr. Dick Burton, HQ, U.S. Army Matériel Command, who shared his knowledge and literature concerning the U.S. industrial base; Mr. Jamie Florence, National Automotive Center, who provided the status of agile manufacturing demonstrations for tank-automotive repair parts; Dr. Greg Foster, National Defense University, who

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Finally, special accolades to Mr. Anthony Robb, CACI Products Company, La Jolla, CA, who arranged to provide the SIMFACTORY II.5/SIMPROCESS software used to build and execute the stochastic models in this research; to Dr. Peter Cherry, Vector Research, Inc., Ann Arbor, MI, who agreed to serve as a long distance academic advisor and freely provided his expert guidance and review; to Dr. James Wilson and Dr. Duncan Holthausen whose advice and comments were extremely helpful; and again to Dr. Thom Hodgson and Dr. Russell King, who granted unlimited access to their offices and their time throughout the conduct of this research.

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List of Abbreviations

AFB	Air Force Base
AFID	Anti-Fratricide Identification Device
ALOC	Air Lines of Communication
AMC	Army Matériel Command
AMEF	Agile Manufacturing Enterprise Forum
AMSAA	Army Matériel Systems Analysis Activity
AR	Army Regulation
ARPA	Advanced Research Projects Agency
ASL	Authorized Stockage Level
BDAR	Battle Damage Assessment and Repair
CAA	Concepts Analysis Agency
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CATIA	Computer Aided Three-dimensional Interactive Application
CEM	Concept Evaluation Model
CENTCOM	Central Command
CONPLANS	Concept Plans
CONUS	Continental United States
CRAF	Civil Reserve Aircraft Fleet

D-to-P	D-Day to Production-Day
DA	Department of the Army
DA PAM	DA Pamphlet
DARCOM	DA Readiness Command (now AMC)
DARPA	Defense Advanced Projects Research Agency (now ARPA)
DLA	Defense Logistics Agency
DSLIE	Defense Logistics Studies Information Exchange
DOD	Department of Defense
FFI	Failure Factor I
FFII	Failure Factor II
FFIII	Failure Factor III
FFIV	Failure Factor IV
FM	Field Manual (U.S. Army publication)
FY	Fiscal Year
GAO	General Accounting Office
GDLS	General Dynamics Land Systems
GDP	Gross Domestic Product
GEM	Generalized Emulation of Microcircuits
GNP	Gross National Product (revised as GDP)
IBM	International Business Machines
IC	Integrated Circuit
IPPD	Integrated Process and Product Development

MANTECH	Manufacturing Technology (An OSD Office)
MPL	Mandatory Parts List
NATO	North Atlantic Treaty Organization
NEA	Northeast Asia
NG	National Guard
NMCS	Not Mission Capable [due to lack of required] Supply
NSN	National Stock Number
NVL	Night Vision Laboratory
OPLANS	Operations Plans
OSRAP	Optimum Stockage Requirements Analysis Program
OSD	Office of the Secretary of Defense
PC	Personal Computer
PEACE	Production Expansion/Acceleration Capability Enhancement
PLL	Prescribed Load List
RAM	Reliability, Availability, and Maintainability
SAIC	Science Applications International Corporation
SESAME	Selected Essential Item Stockage for Availability Method
SPARC	Sustainability Predictions for Army Spare Components Required for Combat
SS	Steady State
STOCEM-3	Stochastic Concepts Evaluation Model-Phase III
SWA	Southwest Asia

TAA	Total Army Analysis
TACOM	Tank-Automotive Command (U.S. Army)
TAIBAM	The Army Industrial Base Assessment Model
TAV	Total Asset Visibility
TM	Technical Manual (U.S. Army Publication)
TPFDL	Time Phased Force Deployment List
TPFDD	Time Phased Force Deployment Data
TSI	Test Systems, Incorporated
U.S.	United States
WRS	War Reserve Stock (or Stockage)
2X in 60 Days	Double Production Rate from X to 2X within 60 Days

Security Classification Information

The information contained in this study was obtained from individually unclassified sources. The scenarios for Northeast Asia and Southwest Asia are authentic. The data used to define the range of the mesh used to generate notional parts with failure factors which span the range of failures of actual repair parts are authentic. However, the number of Abrams tanks assigned to a battalion or armored cavalry regiment as well as other actual distribution factors for the Abrams system have been purposefully perturbed to avoid the possibility of creating classified information representative of the capability of the United States to wage war in these scenarios. The methodology presented may be used with actual data for classified studies in other appropriate circumstances.

The concatenation of data--even through they may be from individually unclassified sources--may aggregately constitute classified information or, given appropriate knowledge, be used to synthesize classified information. Researchers are reminded that results obtained using this methodology would appear to be classified if actual data were used to project the operational readiness of major weapons systems in a major regional conflict in Northeast Asia, Southwest Asia, or any combination thereof.

Preface

In a fit of exasperation during World War II, Prime Minister Winston Churchill reportedly quipped, "In the end, Americans will do the right thing--after having first exhausted all other alternatives." Using this quote and reminding his audience of the inauspicious results following the major reductions in United States (U.S.) military forces after World War II and Vietnam, Secretary of Defense Dr. William J. Perry told his audience in November 1993 that the post–Cold War major reductions in U.S. military forces should be the occasion when we do the right thing (Program Management, 1995). This year [1995] Mr. Norman R. Augustine, President of Lockheed Martin Corporation, has given public speeches in which he notes that military acquisition budgets have fallen 70 percent from their peak in 1987. He observes that 1.3 million civilian jobs have been lost in the defense sector and predicts that more job losses will occur. "For our industry, this is 1929" (Mintz, 1995).

Manufacturing is also experiencing an evolution--some would say revolution--in methods and practices which are simultaneously leading to greater efficiencies and interdependencies on a national, perhaps global, scale. Production on demand as opposed to production for inventory is becoming possible due to the ever-increasing pace of advances in communications, computer, and manufacturing technologies. Characterized by

an industry-led consortium in 1991 as "agile manufacturing" (Nagel & Dove, 1991a, 1991b), this evolution of the U.S. industrial base will influence the efforts to manage the drawdown of military forces in the post–Cold War era.

The synergy of these two events is analyzed to project the potential implications of Class IX repair parts availability on the readiness of major weapons systems during projected major regional conflicts. As technology in the commercial "agilized" industrial base races ahead, the remains of the defense industrial base for weapons systems that are no longer in production will survive by producing repair parts. In this environment, every critical repair part that does not have a commercial equivalent market, could be a sleeping time bomb with the potential to significantly reduce the operational availability of a major weapons system during a two nearly simultaneous major regional conflict scenario. The margin for error afforded logistics planners during the Cold War era due to active weapons system production lines and inventories designed to support a major, protracted ground war with the Warsaw Pact in Europe is becoming much leaner in the post–Cold War era. Including environmental and recently derived combat failure factors in addition to normal demand history failures (adjusted for an increase in operational tempo during war) in a nearly simultaneous Northeast Asia and Southwest Asia major regional conflict scenario results in 95% prediction intervals that indicate the possibility of a repair part demand that is over eight times that which would be expected during an equivalent period of peacetime.

Careful consideration of the inventory and production capacity maintained for critical repair parts for major weapons systems will become increasingly important during

the next decade. A failure to adequately manage the balance between inventory and the industrial base capacity to produce repair parts could lead to severe degradation of combat readiness on the battlefield due to lack of individual repair parts. In an era of tight Department of Defense budgets, a popular notion of adapting commercial practices in Department of Defense acquisitions, and the emphasis in the commercial industrial sector to implement just-in-time inventory methods, arguing for funds to support the purchase of contingency manufacturing capacity or the maintenance of a high inventory level will be challenging. The potential result of less than diligent scrutiny of every repair part is inadequate repair part support to units on future contingency battlefields.

The events that are combining to produce this synergy are described in Chapter I through Chapter XII. The synthesis of a problem definition within the framework of these events is provided in Chapter XIII. Modeling objectives, model development details, and simulation results follow in Chapter XIV through Chapter XXII. Analyses of the simulation results are in Chapter XXIII.

The Implications and Risks of an Agile Manufacturing Industrial Base to U.S. Army Matériel Readiness for Rapid Reaction Major Regional Conflicts

I. Background.

Dynamic forces are working to change the basic structure of the industrial base of the United States (U.S.) in the coming decade. Chief among these forces is the market-driven, technology-enabled progression of manufacturing from a mass production environment toward a more efficient, interdependent "agile manufacturing" environment. Just as the rise of mass production manufacturing transformed our society in the past, agile manufacturing has the potential to profoundly affect the social and economic structures of our society today (Goldman & Nagel, 1993). The competitive foundation and characteristics, manufacturing enterprise elements, and implied enabling subsystems that are required for an agile manufacturing enterprise, and thus define the requirements for agile manufacturing, already exist in various states of maturity in the U.S. industrial base. These agile enterprise characteristics are presented in Figure 1 (Nagel & Dove, 1991b). Only recently identified as a viable paradigm in its own right, agile manufacturing requires attention in addition to factors cited in the litany of literature already highlighting dangers and shortfalls of the present and projected defense industrial base (Henning & Kusima, 1990; Hardy, 1993; Kanter & van Atta, 1993; Leighton, 1992; Porter, 1992; Rogers, 1991; Shames, 1992).

COMPETITIVE LEADER 2006-THE AGILE ENTERPRISE

COMPETITIVE FOUNDATION & CHARACTERISTICS	*MANUFACTURING ENTERPRISE ELEMENTS*	*IMPLIED ENABLING SUB-SYSTEMS*

•COMPETITIVE FOUNDATION

- Continuous Change
- Rapid Response
- Evolving Quality Journey
- Environmental Responsibility

•ENTERPRISE CHARACTERISTICS

- Concurrence
- Continuous Education
- Customer Responsive
- Dynamic Multi-Venturing
- Employees Valued
- Empowered Individuals In Teams
- Environmentally Benign
- Flexible (Re-) Configuration
- Information Accessible & Used
- Knowledgeable Employees
- Open Architecture
- Optimum First-Time Design
- Quality Over Productive Life
- Short Cycle Time
- Technology Leadership
- Technology Sensitive
- Total Enterprise Integration
- Vision-Based Management

Manufacturing Enterprise Elements

- Business Environment
- Communication & Information
- Cooperation & Teaming Factors
- Enterprise Flexibility
- Enterprise-Wide Concurrency
- Environmental Enhancement
- Human Elements
- Subcontractors & Supplier Support
- Technology Deployment

Implied Enabling Sub-Systems

- Continuous Education
- Customer Interactive Systems
- Distributed Databases
- Empowered Individuals & Teams
- Energy Conservation
- Enterprise Integration
- Evolving Standards
- Factory America Net
- Global Broadband Network
- Global Multi-Venturing
- Groupware
- Human-Technology Interface
- Integration Methodology
- Intelligent Control
- Intelligent Sensors
- Knowledge-Based Systems
- Modular Reconfigurable Process Hardware
- Organizational Practices
- Performance Metrics & Benchmarks
- Pre-Qualified Partnering
- Rapid Cooperation Mechanisms
- Presentation Methods
- Simulation & Modeling
- Software Prototyping & Productivity
- Streamlined Legal Role
- Supportive Accounting Metrics
- Technology Adaptation & Transfer
- Waste Management & Elimination
- Zero-Accident Methodology

Iacocca Institute - Lehigh University

Source: Nagel & Dove, 1991b

Figure 1: Agile Enterprise Characteristics

Simultaneously the disintegration of the Warsaw Pact and the Union of Soviet Socialist Republics has led to large current and projected U.S. Department of Defense (DOD) budget reductions and a concomitant downsizing of the U.S. Armed Forces (Skibbie, 1994; Merritt, 1994). The blueprint for the drawdown is the Bottom Up Review. The Bottom Up Review is the result of an assessment ordered in early 1993 by Secretary of Defense Les Aspin to determine the post–Cold War requirements for U.S. military forces. After evaluating the completed Bottom Up Review in September 1993, [then] Deputy Defense Secretary William Perry concluded that the defense industrial base would have to shrink to less than 50% of its high mid-1980s level due to anticipated decreased DOD budget outlays (Velocci, 1993b). In a speech later that year, Secretary Perry warned a group of defense industry executives that "four years from now [1993], two-thirds of you won't be here, or you'll be two-thirds smaller" (Skibbie, 1994, p. 10).

The total DOD budget in terms of constant dollars and as a percentage of Gross National Product (now called Gross Domestic Product) has been declining markedly in recent years as shown in Figure 2 and Figure 3 (Garcia, Glocke, & Johnson, 1994). The total DOD budget as a percentage of Gross Domestic Product is projected to reach a 50-year low in fiscal year (FY) 1997. As DOD spending on weapons systems and force structure are reduced in response to a perceived reduction in the size and scope of potential worldwide situations that would possibly require a U.S. military commitment, the industrial

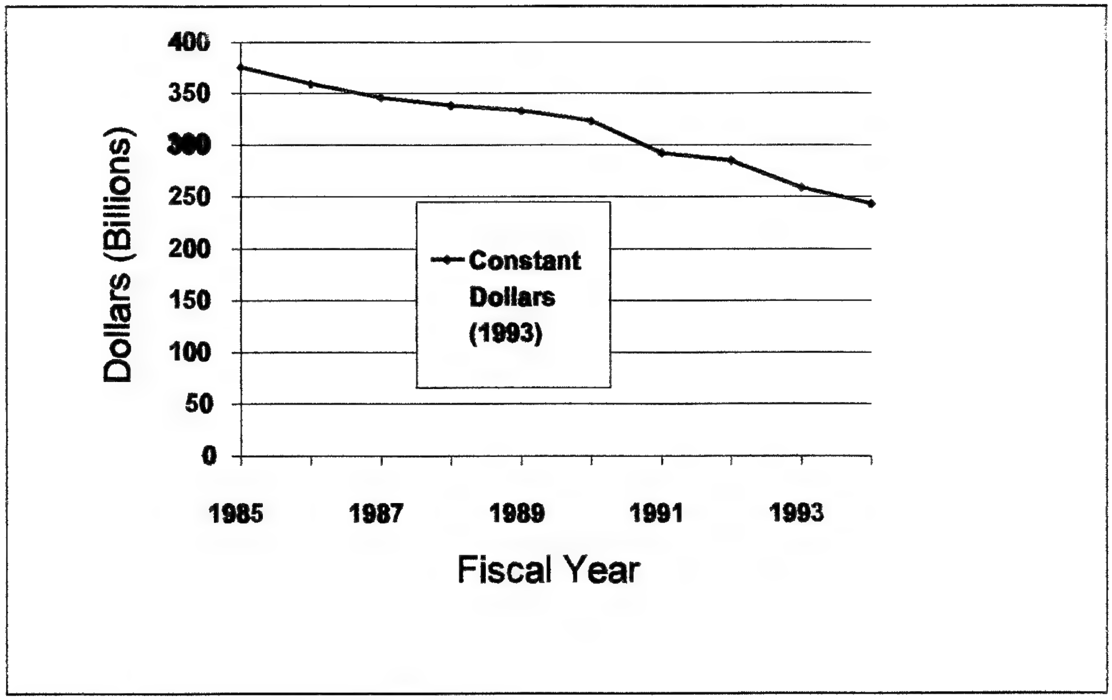


Figure 2: DOD Budgets 1985-1994

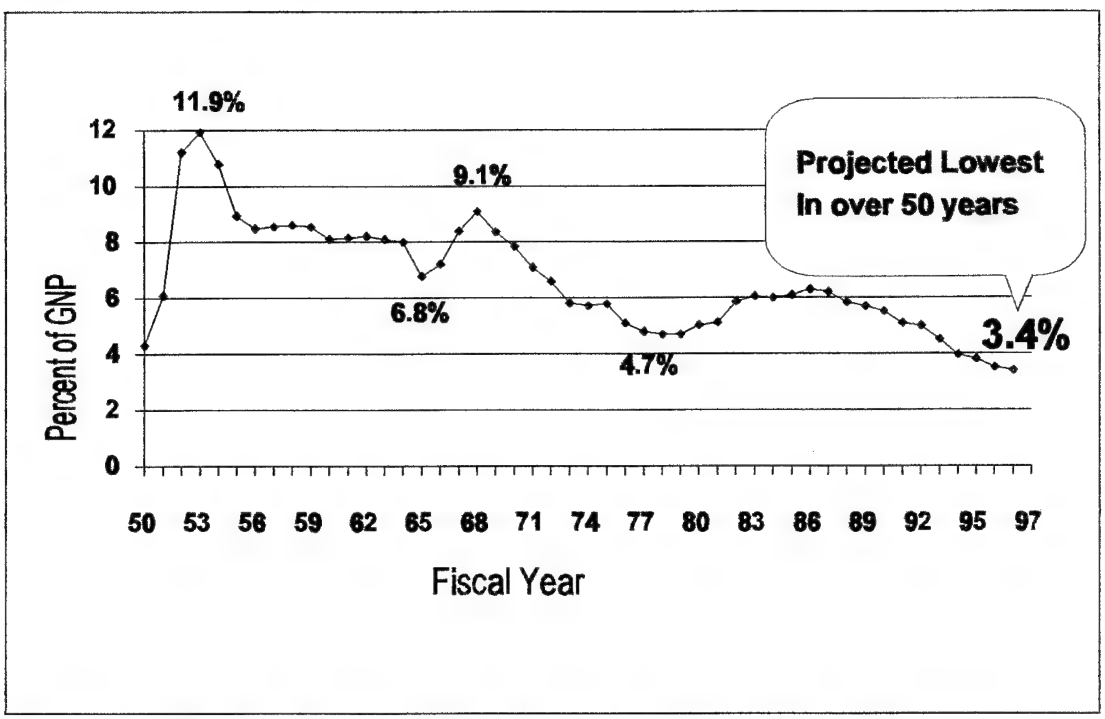


Figure 3: DOD Budget as a Percentage of Gross National Product

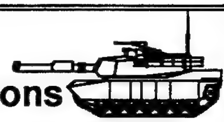
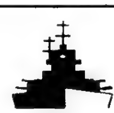
base that provides goods and services to DOD will also contract. Defense industry consolidation and size reduction are already evident. For instance, Northrop Grumman Corporation, formed in 1994 by the merger of Northrop Corporation and Grumman Corporation, announced on September 22, 1994, that it would eliminate 9,000 employees out of its total of 47,500 employees [a cut of almost 19%] within 15 months (Northrop, 1994). The total number of jobs projected to be lost due to the proposed reduced defense budgets is estimated to be between 800,000 and 1 million during the period 1993 to 1997 (Kaitz & Jankowsky, 1993, p. 3).

The impact on the authorized number of active duty armed forces personnel is similar. From a total strength of approximately 2.3 million people serving on active duty in 1987, the Bottom Up Review results in an authorized FY99 personnel strength of fewer than 1.5 million people, a 33 percent reduction. A breakdown of the FY99 authorized personnel strength by armed service is included in Table 1 (Hudson, 1995). The authorized combat force structure for the principal armed services in FY99 resulting from the Bottom Up Review is shown in Table 2 (Morrocco & Fulghum, 1993). The leadership of the U.S.

Table 1: FY99 Military Strength

Armed Service	Personnel Strength
Army	495,000
Navy	394,000
Air Force	390,000
Marine Corps	174,000
Total	1,453,000

Table 2: Projected Force Structure Through 1999

Armed Force	FY 90	FY 93	Bottom Up Review
ARMY 			
Active Divisions	18	14	10
NG Div Equivalents	10	6 (+2 Cadre)	5 +
AIR FORCE 			
Active Fighter Wings	24	16	13
Reserve Fighter Wings	12	12	7
NAVY 			
Aircraft Carriers	15 + 1	13 + 0	11 + 1
Active/Reserve Air Wings	13/2	11/2	10/1
Ships	546	443	346

Army decided to achieve the ten-division, 495,000-soldier force structure by the end of FY96 instead of waiting until FY99 (Peters, 1995; Triumph, 1995). By front-loading the drawdown, the Army leadership intends to save money in personnel accounts that can be applied to increase budget allocations for force modernization accounts. The remaining ten Army Divisions and their locations are cataloged in Table 3. A significant fact to observe is that for the first time since World War II, the U.S. Army will have only parts of three divisions forward deployed in regions outside the continental U.S. Total Army troop strength deployed in Europe has been reduced to approximately 95,000 soldiers from a level of 210,000 soldiers in 1990.

Given that we maintain a military force and have intentions to use it if

Table 3: The Ten Division Army of FY 1996

Division Name	Location	Nickname
1st Infantry Division (Mechanized)	Wuerzburg, Germany	"The Big Red One"
2nd Infantry Division	Camp Red Cloud, Korea	"Indianhead"
3rd Infantry Division (Mechanized)	Ft. Stewart, GA	"Marne Division"
4th Infantry Division (Mechanized)	Ft. Hood, TX	"Ivy Division"
10th Mountain Division (Light Infantry)	Ft. Drum, NY	"Mountaineer"
25th Infantry Division (Light)	Schofield Barracks, HI	"Tropic Lightning"
1st Cavalry Division	Ft. Hood, TX	"The First Team"
1st Armored Division	Bad Kreuznach, Germany	"Old Ironsides"
82d Airborne Division	Ft. Bragg, NC	"All American"
101st Airborne Division (Air Assault)	Ft. Campbell, KY	"Screaming Eagles"

necessary, plans for employing it must be carefully prepared. These plans must include due consideration of these fundamental requirements for the successful application of U.S. military forces in combat:

(1) A popular national will to support the deployment of the military force
(2) An adequate quantity and quality of personnel, equipment and ammunition
(3) Means of transportation to move the forces as needed
(4) The ability to continuously provide the forces with all critical supplies to maintain combat capability (Training, 1985).

The last requirement is of particular interest, as it applies to the manner

in which supplies of repair parts in both quantities and types required will be provided from inventory and factory production to the military combat users. Basing the majority of the U.S. Army within the continental United States underscores the need for adequate repair part planning for contingency operations on other continents. Bringing the right quantity of the right kinds of repair parts can make a significant difference in the combat operational readiness of deploying forces that are otherwise dependent on supplies to be sent from the continental U.S. The transition of the U.S. industrial base to agile manufacturing practices and structures and the reduced size of the industrial base supporting military requirements must be evaluated together to ensure that the supply matériel readiness[1] of combat forces, and thus their combat power, can be maintained.

The apparent advance of agile manufacturing in the industrial base and the absolute victory of capitalism over communism in the Cold War [a victory which is enabling the reductions in military spending and force structure], are each laudable. In combination, however, these events may harbor a subtle and potentially dangerous synergy concerning repair parts for military weapons which must be addressed by the U.S. Army, and the other armed forces. By design, the Bottom Up Review force structure represents the minimum combat potential required to support credibly the national interests of the U.S.

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[1]The degree to which combat forces are able to avoid nonoperational combat equipment by having critical repair parts available when required is the measure of supply matériel readiness (AR 220-1, 1993; AR 750-1, 1991).

throughout the world. Agile manufacturing practices (discussed in Chapters III and IV) will absolutely expand the options available for providing the required repair parts for U.S. Army forces committed to combat. The prospect of reducing or eliminating most war reserve inventory and the accompanying reduction in the costs associated with purchasing, storing, and maintaining inventory as well as elimination of the risks of obsolescence is exciting. Agile manufacturing may open the door to the possibility of relying on industrial capacity residing in agile manufacturing facilities to support contingency requirements for military repair parts. As these changes unfold in both the industrial base and the Army budget, logisticians must be vigilant to ensure that the availability of repair parts is adequate to support operational readiness of military forces committed to combat.

It is the intent of this research to demonstrate a methodology that will enable logistics policy makers to assess (1) the demand profiles for repair parts required to support a major weapons system in a given two nearly simultaneous contingency scenario and (2) compare the impacts of alternative inventory and production capacity policies on the operational availability of a major weapons system during the scenario. A stochastic modeling methodology is developed and used which makes use of traditional reliability based failure factors as well as recently developed combat failure factors. Including the combat failure factors in the model leads to predictions of significantly increased demand for some repair parts over the quantity

expected during peacetime. In fact the upper limit of the 95% Prediction Interval for the representative repair part with the most strenuous failure factor profile represents a cumulative demand that exceeds the expected cumulative peacetime demand during an equivalent time period by over eight times. This may be a part of the explanation for the reported unit-level shortages of repair parts in U.S. Army tank battalions during the 100-hour ground war phase of Operation Desert Storm during the Persian Gulf War.

II. Potential Conflicts

Currently, there are no potential U.S. adversaries, with the possible exception of the People's Republic of China (Triplett, 1994), that could seriously challenge conventional U.S. military power. Future emergence of a significant adversary with conventional forces of the strength once maintained by the former Soviet Union would require a minimum of several years--more likely a decade--to accomplish. Such an emerging potential military threat would certainly be detected by U.S. intelligence resources early enough to allow adequate time for an orderly U.S. reaction (Hardy, 1993; Graham, Kanter, Van Atta, Hoyler, & Nauta, 1993). Given a time horizon measured in years, the above situation is not a rapid reaction contingency and therefore is not further analyzed in this study.

However, the Bottom Up Review does pose the continued possibilities of rapid reaction contingencies on the scale of Operation Desert Shield and Operation Desert Storm during the Persian Gulf War[2] of 1990-1991. These contingencies do not include the luxury of a long-term warning that would allow for the mobilization of the industrial base. They can occur rapidly without prior warning. The duration of these contingency conflicts are measured in terms of six months or less. Time lines for these contingencies do not assume that the U.S. will mass combat forces in a combat theater prior to hostilities. It is

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[2]A brief chronology of major events during the Persian Gulf War is provided as Appendix A for reference.

assumed that any potential future aggressor has learned by casual observations of the Persian Gulf War the fallacy of allowing adversaries an uninhibited six month opportunity to mass combat forces (Schwartz, 1992).

The most stressing scenario theorized in the Bottom Up review assumes a rapid reaction requirement to conduct two nearly simultaneous major regional conflicts. The validity of this scenario was reaffirmed by the Joint Chiefs of Staff in February 1995 when they wrote in the National Military Strategy of the United States of America that, "The core requirement of our strategy as laid out in the Bottom Up Review is a force capable of fighting and winning two major regional conflicts nearly simultaneously" (National, 1995). These two major regional conflicts are identified as the Northeast Asia (commonly referred to as NEA) scenario and the Southwest Asia (commonly referred to as SWA)

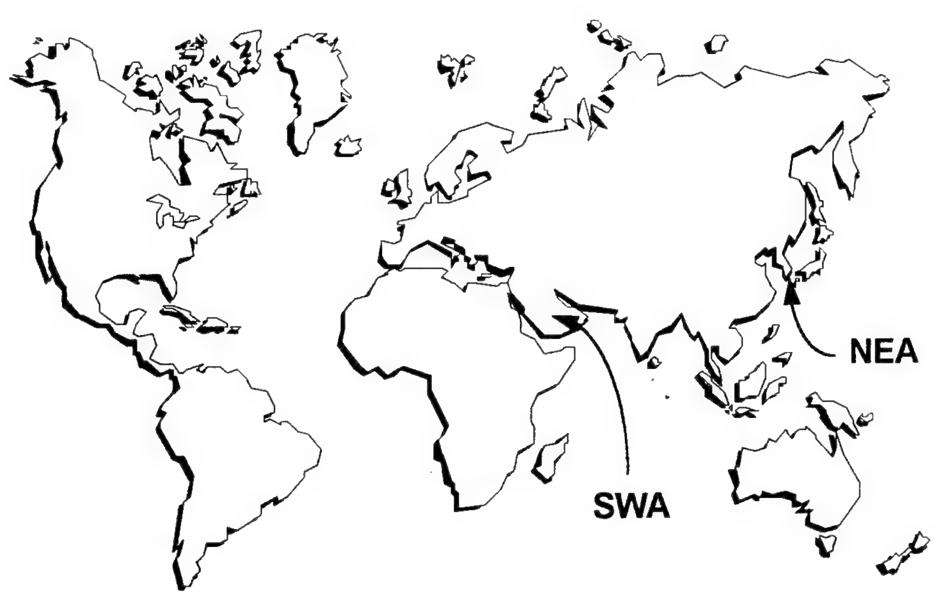

Figure 4: Potential Major Regional Conflict Locations

scenarios (Morrocco & Fulghum, 1993). The Southwest Asia and Northeast Asia geographic regions are indicated in Figure 4. The Northeast Asia scenario is essentially a conflict involving an invasion of South Korea from North Korea. The Southwest Asia scenario involves an aggression somewhere in the Persian Gulf region. Details from these scenarios are used as input data in this research.

III. Agile Manufacturing

Agile manufacturing is a proposed natural post–mass production era evolution of industrial economies. Early references to the term "agile manufacturing" in the context of this research were published by Hamel and Prahalad in their article "Strategic Intent," in Harvard Business Review (1989) and by Lingus in Manufacturing Engineering (1990). However, the idea of agile manufacturing as a production, management, and engineering philosophy was widely introduced and solidly founded in 1991 as a direct consequence of an **industry-led** consortium chartered by the Office of the Secretary of Defense Manufacturing Technology (MANTECH) Office. The consortium consisted of business executives from a number of Fortune 500 companies who were facilitated by the Iacocca Institute at Lehigh University. The team members met for three months in mid-1991 at an expense of some $500,000 in public and private funds to contemplate the future of manufacturing in the U.S. and to plot a course for future success in a global market. The resulting two-volume report, 21st Century Manufacturing Enterprise Strategy (Nagel & Dove, 1991a, 1991b), began a whirlwind of press reports, management consultant seminars, and general industry interest in agile manufacturing that continues today.

To proponents, agile manufacturing represents nothing less than an opportunity to regain American preeminence in manufacturing in previously lost markets, such as consumer electronics, and gain or maintain world

leadership in others. To the printed circuit board maker, a shift to agile manufacturing may involve only a short step from current state-of-the-art production methods. In other less high-technology industry sectors, agile manufacturing may represent a radical departure from present practices for both management and labor.

The enabling manufacturing technologies required for agile manufacturing have been rapidly maturing. One executive noted that "Agile manufacturing is a concept that will accelerate into the next century because flexible, modular, multi-task machine cells and systems already are major players in that evolution" (Papke, 1993). In the field of robotics, for example, the state of the art of robotic end effectors has improved dramatically in the past eight years. Modern end effectors can be designed with almost human dexterity ("Adaptive robotic," 1993; "Aces," 1992, "Fast, agile," 1987). Simultaneously the market driven requirement for seamless interaction of software and hardware across the computer industry has met with great acceptance (Lopes, 1992). This seamless hardware and software interface is further leveraged by the explosion of telecommunications capabilities to link designers and producers around the world instantly (Valovic, 1992).

The agile enterprise gains a competitive edge versus conventional manufacturers on the basis of low unit costs for high-quality, highly customized, small production lot products with a very compact demand-to-satisfaction time (Youssef, 1992). The use of (1) instant high bandwidth

worldwide communications, (2) worldwide transportation, (3) fast, concurrent design engineering systems (CAD/CAM/CAE), and (4) flexible factories (coordinated and matured flexible manufacturing systems) combine to allow the existence and continued evolution of agile manufacturing (Nagel, 1993). In short:

> *Agile manufacturers of the future will be characterized by cooperativeness; rapid production of high-quality, customized goods, decentralized decision-making power, and an information infrastructure that links customers, manufacturing, engineering, marketing, purchasing, financing, sales, inventory, and research. Speed in responding to market will be the principal virtue of agile companies, which will produce-to-order rather than stock-and-sell* (Austin, 1994, p. 34).

A. Evidence of Agile Practices. Contemporary examples of evolving agile-manufacturing-like practices in the commercial passenger aircraft, clothing, personal computer, and integrated circuit industries as well as an exceptional example from the Persian Gulf War are presented below.

1. Boeing 777 Airliner. The Boeing 777 is the first commercial passenger aircraft designed and produced by the Boeing Aircraft Company without the requirement to build a physical mockup. The 777's 85,000 components and over four million parts have all been designed into the aircraft using eight IBM mainframes, 2,200 work stations, and IBM CATIA CAD/CAM software. Each aircraft is individually tailored to meet differing customer preferences for such items as galley design, seating, cargo capacity, engines, fuel tanks, and navigation equipment. A digital "as built" database of each

aircraft produced records every detail. (Garcia, Glocke, & Johnson, 1994, pp. 89-91). Boeing delivered the first production 777 to United Airlines in May 1995.

2. Levi's Personal Pair Jeans. Levi Straus & Company started a service called Levi's Personal Pair Jeans for women in the summer of 1994. For a fee of ten dollars over the retail price, a customer can have any variety of colors available in the Levi styles 501, 505, or 512 jeans made to her exact dimensions. Her custom jeans are returned to the store where she placed the order for pickup. Direct delivery from the factory to the customer's address via Federal Express is available for an additional charge of five dollars. In an industry where "$25 billion worth of manufactured clothing each year either goes unsold or sells only after severe markdowns," Levi Straus & Company are pioneering the change to individually tailored goods and services for their mass marketed brand-name jeans. The implications are awesome. "It [Levi's mass customization] has the potential to change the way people buy clothes, and it will allow stores to cut down on inventory." At present, the demand-to-satisfaction time is 2.5 weeks even using the Federal Express delivery option. Even so, the sales of women's jeans at the first store to offer the Levi's Personal Pair Jeans service have increased 300% within a few months and the rate of customer returns of custom fit jeans is much lower than for off-the-rack jeans (Rifkin, 1994).

3. Personal Computer Manufacturers. Dell and Gateway 2000, both

mail-order Personal Computer (PC) makers, rely on customer orders by telephone to provide the production schedule in their factories. In the last year, they have been joined by Compaq Computer Corporation, a company that sells by mail-order and through retail merchants. "In three years [1992-1994], Compaq has doubled the number of PCs produced per square foot of factory space. The number of machines produced per worker has jumped 50 percent . . . . By the end of next year [1995] the company intends to stop relying on forecasts and switch mainly to three-person cells [and away from assembly lines] that will produce only what customers order." For Compaq, this transition has led them from a troubled number three PC maker in 1993 behind Apple and IBM to become Dataquest's projection as the number one PC maker in the world in 1994 (Levin, 1994). Compaq achieved that goal and remains first in the world through the second quarter of 1995 with sales of 1.45 million PCs, up 25 percent from a year ago (Compaq, 1995).

4. Generalized Emulation of Microcircuits. In an effort to provide replacements for integrated circuits (ICs) in aging military equipment when there is not a source for procurement, the GEM Program is developing generalized emulation of microcircuits (GEM) ICs. GEM ICs are able to emulate the logic of the otherwise nonavailable IC's that they replace. ". . . over sixty-seven percent of the 115,000 microcircuit National Stock Numbers (NSNs) in the federal catalog can be emulated using GEM single biCMOS gate array technology." The goal of the GEM Program is to "provide nonprocurable

ICs on demand" (Christensen, 1994). The demand for GEM ICs is driven by the disparate lag between the rapid change in the state of the art in the microelectronics industry and the relatively much slower pace of upgrading military equipment that is already produced and in use in the armed forces.

5. Anti-Fratricide Identification Device. A final example supporting the supposition that agile-manufacturing-like practices are occurring in the industrial base is selected from among those that occurred during the Persian Gulf War. It is the case of the Anti-Fratricide Identification Device (AFID). A chronology of the AFID development and deployment to the U.S. forces in Operation Desert Storm is contained in Table 4. As the name implies, the AFID was designed to allow friendly combat forces to identify positively each other on the battlefield and thereby avoid "friendly fire" accidents.

Previously nonexistent, the AFID was conceived and designed by employees of Test Systems Incorporated (TSI) of Hudson, New Hampshire, after they learned of "friendly fire" accidents during media coverage of the war. They discussed the situation of friendly fire accidents among themselves, determined that they had a potential solution, and the AFID concept was born on February 4, 1991. At 2:15 AM on February 25, 1991 the first 100 production AFID devices (out of a DOD order for 10,000) departed Dover Air Force Base, Delaware, for Saudi Arabia. This is a phenomenally blinding pace of "21 Days Concept to Combat." Under normal conditions, the development and production of a device like the AFID would have been measured on a

Table 4: AFID Development Chronology, February 1991

Day - Activity	Day - Activity
4 - TSI conceives solution to "friendly fire" incident	19 - In just 96 hours, first 10 fielded following hundreds of schematic, design, and mechanical modifications for final flight tests in Arizona, and demonstrations at the Pentagon and "CENTCOM"
5 - TSI solicits military interest	21 - Testing complete at MCAS Yuma, Arizona. A few modifications quickly implemented
6 - Congressman Swett's office contacted to help idea get attention in Washington, DC	Mass production begins with first lot of 100 units due at Dover AFB, Delaware, in less than 72 hours for delivery to Kuwaiti Theater
7 - DARPA contacts TSI, requests first prototype (P1) immediately	22 - Worldwide acquisition network started to find "off the shelf" material to build 9,900 more AFIDs. In fewer than 24 hours 100+ vendors brought into the process
8 - TSI delivers AFID after working all night. DARPA impressed, requests P2 with minor modifications	More than 75 new employees hired
9 - TSI engineers work all weekend on P2	New, larger warehouse acquired
11 - P2 delivered and forwarded to Hurlburt AFB, for testing with 22 other devices under development	Plant begins 24 hour production
13 - Joint Staff decides TSI's quick production capability and cost effectiveness made AFID the near term solution for "Friendly Fire." DARPA directs TSI to build 10 prototypes for further testing ASAP, with a follow-on production run of 10,000	24 - 2200 hours [10 PM] , flight takes off for Dover AFB, Delaware with the first lot of 100 AFID
15 - Engineers from DARPA and the Army Night Vision Laboratory arrive at TSI to assist in design and production	25 - 0215 hours, "Desert Express" flight leaves Dover AFB, Delaware for Saudi Arabia
Planning and acquisition phases begin for large scale production	***21 Days Concept to Combat***
16 - TSI, DARPA and NVL begin flight tests at Ft. Devins	2200 hours, second urgent lot of 66 AFIDs depart plant for Dover AFB
17 - TSI flight testing concluded with results immediately applied to test prototypes	26 - Final urgent lot of 90 delivered to Dover AFB
	27 - Cease Fire called. Another 200 units produced

scale in years. The key to success in the AFID development and production was the use of available off-the-shelf items and commercial standards and specifications instead of military specifications[3]. The AFID was encased in plastic and powered by six ordinary Eveready Energizer "C" cell batteries (Nagel & Dove, 1991a, p. 34). Agile manufacturing advocates project that the time required to duplicate the AFID case in an "agilized" industrial base of the next decade could be cut by as much as a factor of seven, meaning a concept-to-production time of three days (Joint, 1994).

B. Agile Manufacturing Enterprise Forum. The Agile Manufacturing Enterprise Forum (AMEF), located in Bethlehem, PA, is an organization dedicated to championing the cause of agile manufacturing. A legacy of the industry-led consortium that published the 21st Century Manufacturing Enterprise Strategy at the Iacocca Institute in 1991, the AMEF has a standing mission " to increase the pace and scope of the transition to an agile competitive manufacturing community in the United States." The AMEF steering committee includes executives (former and current chief executive officers, presidents, vice-presidents) from companies such as Air Products and Chemicals, Inc., IBM, Texas Instruments, and Hughes Aircraft among its members (AMEF, 1994). As an indication of its viability, it is noted that the

[3]In a memorandum on June 29, 1994 the Secretary of Defense directed that DOD components "use performance and commercial specifications and standards in lieu of military specifications and standards, unless no practical alternative exists . . . ." (Perry, 1994).

Agile Manufacturing Enterprise Forum is sponsoring its 5th Annual Agility Forum Conference March 5-7, 1996 in Boston, MA., with the theme "Becoming Agile by 2000: Ramping Up" (Agility Forum, 1995).

IV. Agile Manufacturing Implications and Effects

The industrial base under the agile manufacturing paradigm is projected to be much more efficient, complex and interdependent than its mass production ancestor. With essentially all potential sources of raw materials, engineering talent, and manufacturing capability and capacity visible via some form of national information superhighway that some have named the "Factory America Net" (Dove, 1992), customers and manufacturers will continually be able to seek and achieve advantageous business arrangements. Although the total scope of the social and economic impacts of agile manufacturing cannot be foreseen, any credible attempt to do future planning involving the overall industrial base must consider the possible impact and promise of agile manufacturing.

Firms successfully adopting agile manufacturing concepts will realize sizeable reductions in inventories and warehouse space required for finished products when compared to that required for the same or like products formerly made in a mass production, economies of scale setting. The economies of scale of mass production are supplanted by an agile manufacturer using the capability of flexible manufacturing equipment to produce quickly individually customized products while maintaining price competitiveness and quality standards. The successful agile manufacturer will begin the design and engineering of products and components with the idea of rapid production or assembly on a family of common flexible manufacturing equipment. Optimum

first-time design is the goal, and is supported by the technologies of virtual reality, simulation, and engineering aids such as CAD, CAM, CAE, and CATIA. Rapid and inexpensive set-up and tear-down operations for flexible production machinery allows smaller lot sizes and decreasing production lead times. These developments, when extrapolated to their extremes, potentially allow the agile manufacturing enterprises to approach the ideal of production on demand. Compaq Computer Corporation, as previously noted, intends to achieve this ideal in its personal computer production in 1995.

As agile manufacturing matures, proponents envision the evolution of virtual companies. Virtual companies consist of an appropriate mix of skilled people and production capabilities that may not be part of the same firm. These components of the virtual company share a common interest in using their unique skill and capabilities to contribute to the design and production of a product or product family in response to a known customer demand. Formed in cyberspace via the information superhighway by mutual consent among the participants, the virtual company manages to gather and focus its talented constituent parts to bid, design, produce and deliver a customer's product rapidly, efficiently, and profitably (Valovic, 1992). Ownership of the constituent parts of the virtual company is of little importance to the process. Each constituent part is striving to be the best among its competitors and therefore the most desirable provider of its particular skill or capability in the agile market place. Once a virtual company fulfills its charter, it may be dissolved as

a matter of routine business practice, thus freeing its participants' obligated resources to be committed as new opportunities become available (Nagel, 1993).

Examples of contemporary virtual companies are not readily identifiable in the literature. Perhaps there is a bit of recalcitrance on the part of potential virtual partners to forge ahead due to the lack of a legal framework. If something goes wrong in a virtual endeavor, who is to blame, who is accountable, and for how much? In some instances antitrust laws legally limit the degree of cooperation possible among some large corporations. These and like obstacles aside, as the advantages of "competitive" cooperation versus the isolation of "do-it-alone" and "in-house" mentalities begin to be felt in the market place, the examples of the virtual enterprise will become more common.

> *As commercial industry becomes more agile, DOD will be able to:*
> *-- Reduce need for in-house production of components*
> *-- Reduce inventories and transportation pipeline*
> *-- Reduce need for standby production capacity. . . . Many of these benefits will flow to DOD even if the [Defense] Department does nothing to change its internal procedures* (Graham, Dahlman, & Gunkel, 1993).

These are the highly desirable expectations and predictions of the performance of an "agilized" industrial base. Indeed, one author extrapolated the promise of improvements in manufacturing technology to the extreme independently of the agile manufacturing development, when he predicted that emerging manufacturing technology . . .

> *makes factory production so responsive that OPLANS and CONPLANS[4] can include mission specific manufacturing requirements. This technology replaces stockpiling with manufacturing capability and intelligent planning. It is capable of sustaining power projection from the factory instead of the warehouse* (Zeller, 1991).

Although few critics of agile manufacturing were found in the literature, the comments of two of the early ones merit discussion. Referring to agile manufacturing as the coming "marketing millennium," Bob Donath in Marketing News (Donath, 1993) wrote, " . . . that 'the agility thing' is destined to be just the next panacea du jour, distinguished more by management prophets than by corporate profits earned." Referring to the 21st Century Manufacturing Enterprise Strategy, Volumes I and II, (Nagel & Dove, 1991a, 1991b), Dr. John Ettlie of the University of Michigan School of Business Administration wrote in Production concerning agile manufacturing that, "I am thankful for one thing: they did not call the report 'intelligent manufacturing'" (Ettlie, 1992).

Although doubting that the degree of profitable cooperation among competitors would occur during the evolution of the industrial base as proponents of agile manufacturing project them, these skeptics do not disagree that future world class manufacturing enterprises will aspire to the efficiencies that proponents ascribe to agile manufacturing.

Another idea that appears implicitly to assume an agile-manufacturing-

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[4]Operations Plans and Concept Plans are military plans that are made in anticipation of possible military operations. Once activated an Operations Plan becomes the basis for actual military actions.

like industrial base was conceived in 1992 when the Defense Science Board introduced the Integrated Process and Product Development (IPPD) concept. The idea was defined while the Defense Science Board was evaluating manufacturing processes and developing the modeling and simulation thrusts for future engineering and manufacturing processes. At that time IPPD was envisioned to be a mechanism that directly linked combat units on the battlefield to the production shop floor (Garcia, Glocke, & Johnson, 1994). In a step toward that goal, in May 1995 the Secretary of Defense in a formal memorandum directed that, "The concepts of IPPD[5] and IPTs [integrated product teams] shall be applied throughout the [Department of Defense] acquisition process to the maximum extent practicable" (Perry, 1995). Given that the U.S. manufacturing sector fully embraces agile manufacturing during the next decade, the Defense Science Board's idea of IPPD may prove to have been visionary.

Understanding the implications of agile manufacturing will become increasingly integral to planning repair part supply and inventory policy in any firm. This is especially true for the U.S. Army because the demands for repair parts during peacetime may be radically different from the repair part demands during a war.

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[5]Secretary Perry defined IPPD as: "A management technique that simultaneously integrates all essential acquisition activities through the use of multidisciplinary teams to optimize the design, manufacturing, and supportability process" (Perry, 1995)--somewhat less sweeping than the Defense Science Board's ultimate vision for IPPD, but a substantial policy shift none the less.

V. Class IX Repair Parts

> *Class IX matériel consists of repair parts and components to include kits, assemblies, and subassemblies (both reparable and nonreparable) required for maintenance support of all equipment except medical matériel. Class IX is demand supported. However, there are a limited number of items that are stocked regardless of demands* (FM 101-10-1/2, 1987, p. 2-164).

The availability of sufficient class IX stocks of repair parts on the battle field is critical to maintaining equipment in operating condition. "The force which is better able than its opponent to recover damaged equipment and return it to service rapidly will have a clear advantage in generating and concentrating combat power" (FM 100-5, 1986, p. 61). This is especially true for modern U.S. Army weapons systems which were designed and produced in an environment when modular "design for discard" components which require replacement upon failure were preferred in weapons systems. The "design for discard" philosophy reduces the overhead burden of personnel and equipment that would be required to repair a larger number of damaged parts. Operational readiness is enhanced by using modular parts given the assumption that the failed component is quickly identified, a new modular part is available and quickly retrieved from inventory, and the old part is simply thrown away without attempts to repair it (Army, 1991, p. 9). The flow of maintenance activities on the battlefield as shown in Figure 5 (Srull, Simms & Schiable, 1989) highlights the potential impact of the availability of repair parts on the operational readiness of a weapons system in a combat theater.

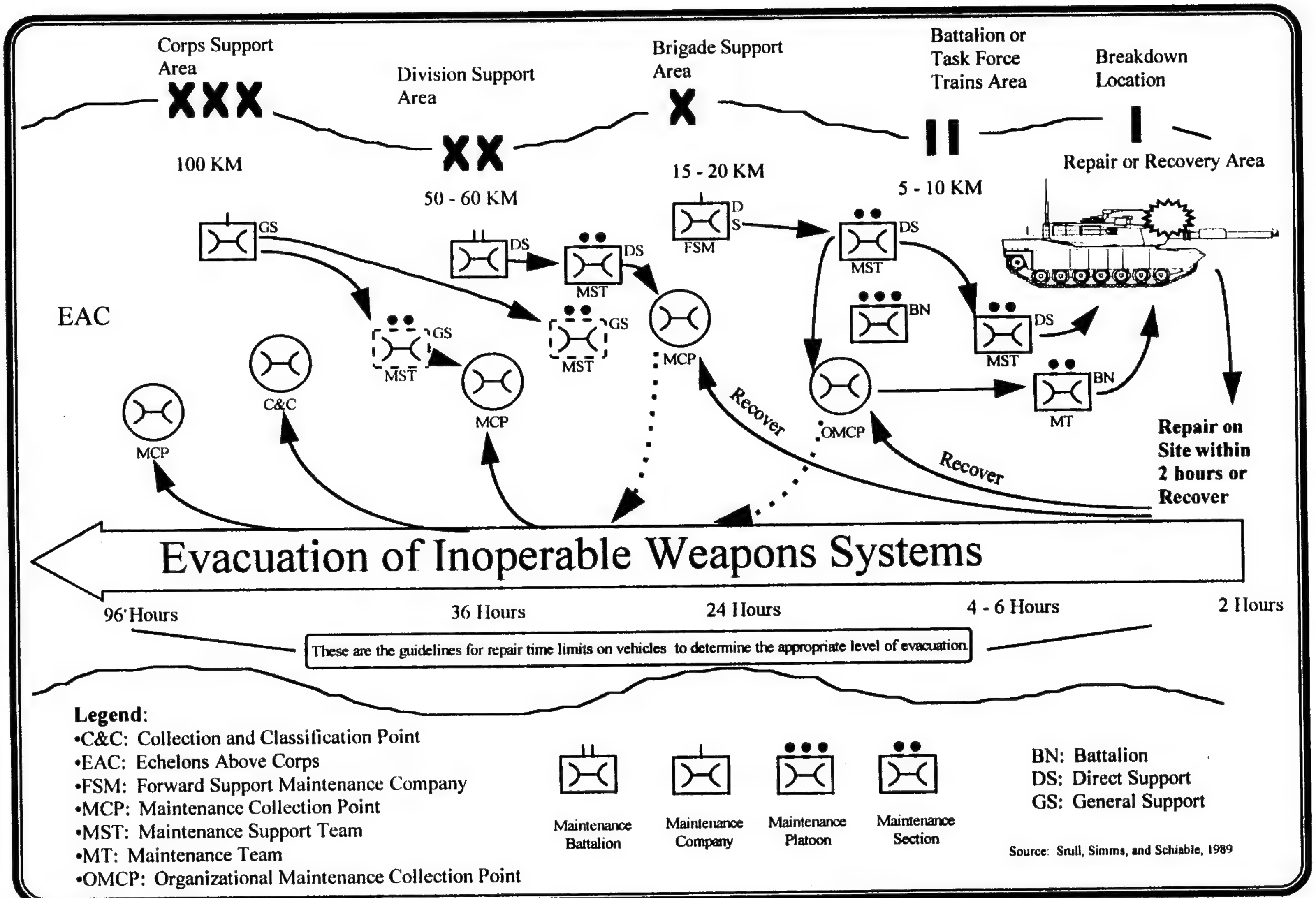

Figure 5: Battlefield Maintenance

Repairs that require parts which are available within approximately six hours of demand will be accomplished and the vehicle retained by the original combat owner. Longer waits typically start a more involved, resource intense, logistics cycle. Although the maintenance concept may change somewhat as the Army adapts its doctrine over the coming years, the importance of having the right part at the right time will remain an integral part of it.

In general, supplies of all items of interest are produced by original equipment manufacturers, aftermarket vendors, or government depots in response to orders from other vendors for production purposes or from DOD components such as the U.S. Army to replenish or initially stock supply inventory. These sources of supply may include foreign-owned firms located in and outside the U.S. in addition to firms owned by U.S. citizens located in the U.S. and abroad. A simple supply flow from the original producer to the battlefield user is shown in Figure 6. Attrition of parts due to loss and damage may occur at any point along the supply flow. Parts are also subject becoming "lost in the system" due to inadequate control and accountability, a phenomenon known as virtual attrition. The supply organization of military units is hierarchical. When a repair part is needed to repair a weapons system, maintenance personnel request the part from the inventory available in the military unit which owns the damaged weapons system. Each level in the supply hierarchy that maintains a supply of repair parts requisitions replenishment stocks from its immediate higher supply source as needed to

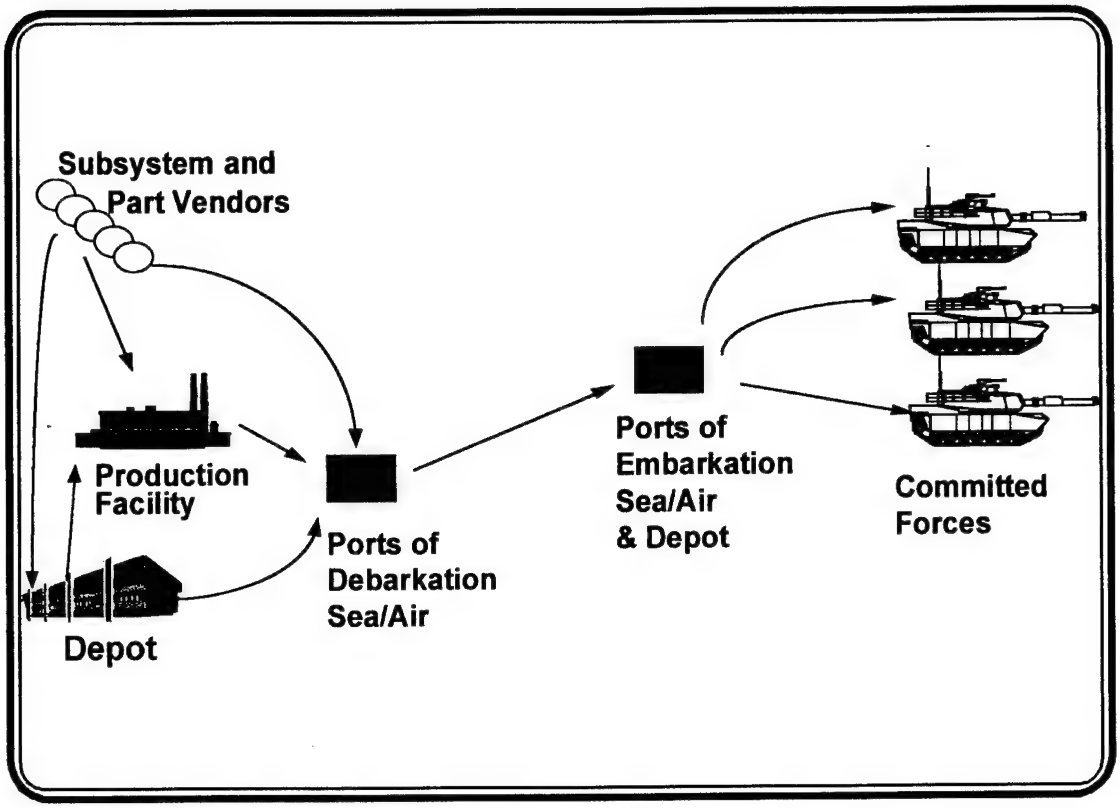

Figure 6: Repair Part Flow

maintain an authorized inventory quantity.

In the endeavor to have required repair parts available when needed, inventories of repair parts in U.S. Army units are maintained at the combat company or battalion level and above. At company or battalion level, the inventory of repair parts authorized is called the Prescribed Load List (PLL). The intent of the PLL is to meet the required peacetime or combat part demands for a specific period of time, usually 15 days, without resupply. The prescribed load list stockage in both type and quantity of parts is driven by peacetime demand history and projected wartime needs. That portion of the prescribed load list designed to support combat requirements is called the

Mandatory Parts List (MPL) and is stocked regardless of demand history. Given (1) a 15-day operational tempo and mission profile of each weapons system, (2) a list of critical repair parts for each weapon system that may be replaced at the unit level, and (3) the observed failure rate from part demand history records, the Inventory Research Office of the Army Matériel Systems Analysis Activity produces the mandatory parts list for each type of weapons system. This is accomplished using the Selected Essential Item Stockage for Availability Method (SESAME) model. The SESAME model results do not include repair part requirements due to direct combat damage. The data used are driven by failure rates for time or amount of weapons system or subsystem use (Kotkin, 1994). These failures due to "wear and tear" during use are referred to as Reliability, Availability, and Maintainability (RAM) failures. SESAME is designed to capture the increase in RAM-related failures due to increased weapons system use during war, but does not consider failures due to combat damage.

The PLL that a unit maintains is also limited by other factors. The total size of the prescribed load list that each unit can maintain is constrained by regulation to maximum of 300 line items, although this limit may be waived by appropriate authorities. Fiscal restrictions may also limit the size of the PLL inventory. If funds are not available to purchase 100% of PLL-authorized inventory, selected shortages occur. A logical constraint on the size of PLL inventory is that combat units must be able to transport 100% of their PLL with

their authorized transportation assets (DA PAM 710-2-1, 1992). PLL repair parts left behind are of no use when they are needed to repair a weapons system deployed on another continent. All items that are authorized for stockage in a PLL are replaceable at the unit level by personnel assigned or in support of that unit.

Higher level organizations (the Division, Corps, and Theater) maintain a similar type of inventory called the Authorized Stockage Level (ASL) which consists of items that are demand supported at their level of supply as well as selected mandatory stockage items.

In anticipation of a surge due to wartime demand, the U.S. Army maintains an inventory of War Reserve Stock (WRS) intended to meet demand until the U.S. industrial base can ramp up production to meet demand (Jones, 1991). The quantity of war reserve stockage required has been historically determined in what is referred to as a "D-Day to Production-Day" or "D-to-P analysis" (Vawter, 1983, p. 24; Richanbach & Bicksler, 1986). A typical diagram of the results of a D-to-P analysis is shown in Figure 7. The D-to-P model diagram simply notes that wartime demand for supplies in greater quantities than industrial production will have to be met from existing inventory stocks until the industrial base can produce sufficient quantities of matériel to meet demand from P-Day forward. A chart outlining the flow of repair parts represented in a D-to-P analysis is provided in Appendix B.

War reserve stock funding is authorized annually by the U.S. Congress

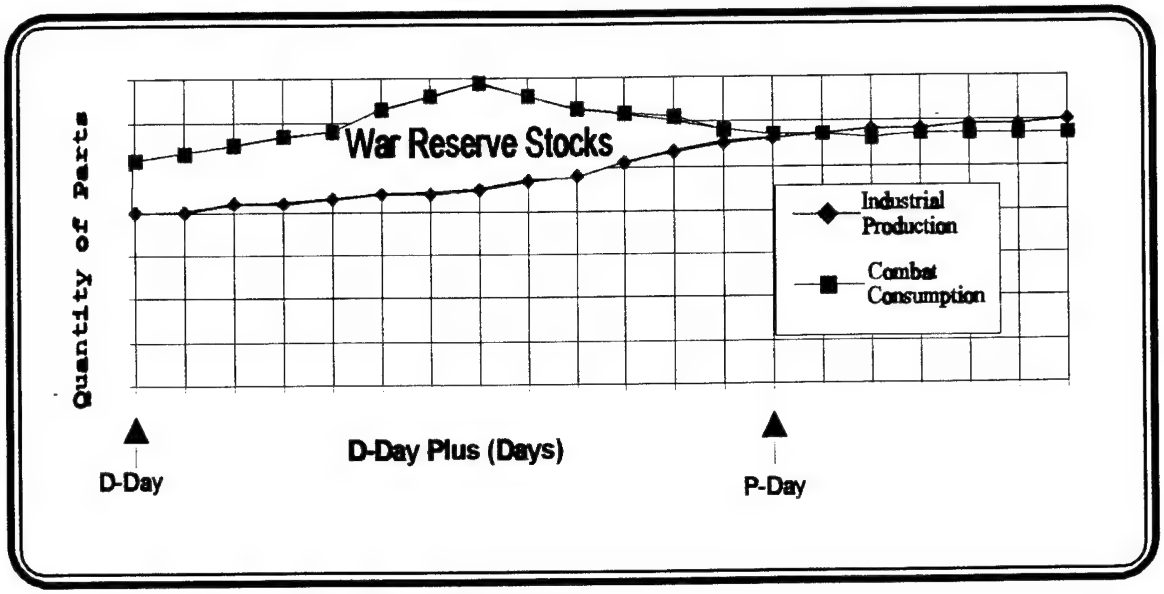

Figure 7: Typical D-to-P Model Result

as a separate budget line item in the DOD Budget. Because war reserve stockage budget requests compete with other national and defense funding priorities, they can be a tempting "bill payer" for other projects of interest in the annual Congressional budget process. As one source commented, the requirements for war reserve can always be reduced if one simply assumes that P-Day is actually closer to D-Day than previously assumed.

Although the media has publicized some notable instances where U.S. Army repair part inventories of items were extremely and unjustifiably high, any generalized perception that excessive or even adequate inventories of war reserve inventories exist is erroneous. For example, in April 1992,

> *the total war reserve requirements for TACOM* [U.S. Army Tank-Automotive Command] *items of support in the category of consumables is $536 million, but only $96 million is funded. Most of the requirement is for combat tracked systems.*
> *. . . [consumables] includes tracks, road wheels, road arms,*

> *shock absorbers (including the unique rotary shock for the Abrams), vee packs (the air filters without which the Abrams engine cannot survive), and space age materials such as plenum seals for the air filtration system on the Abrams. Vee packs, road arms, and road wheels were among the items that were in short supply during Operation Desert Storm and had to be borrowed from production. This is in spite of the fact that the M1 Abrams [war reserve] is funded more fully than any other system at TACOM.* (Decker, Aquino, & Napier, 1992, Part I, p. 13)

Agile manufacturing proponents would argue that the need for war reserve stockage requirements will shrink markedly and eventually be eliminated in the next decade. Indeed no need would exist to expend scarce financial resources for inventory, the overhead required to store and maintain inventory, and risk the possibility of ultimate obsolescence of inventory, given that agilized industries are both willing and capable to produce the required wartime production of Class IX repair parts on demand.

VI. Failure Factors

A. Reliability Based Failure Factors. Three failure factors used in the U.S. Army to predict reliability- and environmental-related part failures are defined in Table 5 (DARCOM, 1983). Failure factors of repair parts are intended to capture anticipated repair part failures throughout the life of a weapons system.

Table 5: Reliability Failure Factor Definitions

Failure Factor I (FFI)	**The expected number of failures of the repair part during peacetime.**
Failure Factor II (FFII)	**The expected number of failures of the repair part during wartime.**
Failure Factor III (FFIII)	**The coded multiplier used to convert FFI and FFII to the expected number of failures for specific geographic areas such as desert, arctic, etc.**

Provisioning planning to estimate repair part failure rates begins in the Concept Exploration and Definition Phase of a new weapons system's development life cycle and continues through the demand development period--the first two or three years after the new weapons system deployment. Based on engineering estimates and other data that may be available, provisioning culminates in the purchase of repair parts in both range and quantity to support required weapons system operational readiness objectives at minimum costs. During the demand development period, the actual history of demands for

each repair part is monitored while parts are stocked at the provisioning estimate quantities. DOD Regulation 4140.1-R, which guides Army provisioning activities, indicates a preference for collecting demand history versus actual weapons system operation in terms of hours, rounds fired, miles driven or other pertinent standards. Where such detailed record keeping is not possible, calendar-based demand calculations are developed (Acquisition, 1995, p. V6). Because a single weapons system may have over 100,000 individual component parts and these weapons systems are routinely deployed at many locations around the world, most Class IX repair part data are collected based on the calendar method. Future weapons systems may have built-in automated data collection and reporting capabilities that will enable more accurate data collection based on operational characteristics instead of calendar time. The data collected during the demand development period is used to calculate reliability-based failure factors for each repair part on the weapons system.

Failure factors for Class IX repair parts are calculated in terms of the expected number of failures of a particular repair part per 100 weapons systems during a period of 365 days. Prescribed Load Lists (PLLs) and Authorized Stockage Lists (ASLs) of repair parts are computed based on demands and therefore generally reflect FFI. Extensive demand history data are available for repair parts for weapons systems such as the Abrams series tank, the Bradley fighting vehicle, the Apache helicopter, and other major

weapons systems produced before and during in the 1980's. Computation of FFII is somewhat problematic. Because the U.S. Army has little actual combat experience using modern weapons systems, there is little empirical wartime data available for use in calculation of FFII. Although the Persian Gulf War in 1991 was a major regional conflict, from a combat logistics point of view the repair part demand data were more representative of a six-month unusually high intensity desert field training exercise followed by 100 hours of combat[6]. To compensate for a lack of empirical wartime demand data, estimates of repair part failure rates based on expected wartime operational tempo increases over peacetime rates are used to scale FFI to estimate FFII.

B. Failure Factor IV. Basing estimates of repair part requirements solely on demand history and increased weapons system operational tempo anticipated during combat overlooks a serious reality of warfare: the objective of military forces committed to war is to win, which implies defeating the enemy. During the conduct of war, opposing forces attempt to use their weapons systems and personnel to attain victory though combat actions. One of the consequences is various levels of damage to those weapons systems as a result of enemy combat actions. The expected quantity of repair parts required as a direct result of combat exposure are not contained in FFI, FFII,

[6]The author is commenting only on the validity of the empirical repair part demand data that were generated during the Persian Gulf War for use in planning for future major regional contingencies and does not intend to denigrate the victory of the U.S.-led Coalition Forces in any manner.

or FFIII. As previously noted, FFI and FFII represent expected peacetime and wartime RAM failure rates and FFIII is used to adjust FFI or FFII for any anticipated extreme environmental conditions. Some major weapons systems may receive combat damage that requires Class IX repair parts to repair. The recent history concerning the development of combat damage failure factors for repair parts is reviewed below.

Two coincidental events in the early 1980s occurred to cause the effective removal of all repair parts explicitly designated for repair of combat damage from PLL and ASL inventories. In July 1983, the Army Staff determined that the cost and volume of Class IX repair parts stocked for potential repair of combat damage in ASL inventories was prohibitive. At that time the Army was fielding new weapons systems while maintaining older weapons systems, effectively doubling the number of weapons systems that the ASLs were responsible to support. To be useful, the ASL had to be transportable. The Army Staff solution was to remove the authorization to stock any repair parts that were designated to be available to repair combat damage. Repair parts that would have been stocked in ASL inventories in anticipation of combat damage repair would instead be maintained in War Reserve (Butler & Bain, 1987; Steiner, 1989).

An earlier unrelated decision to forbid repair of combat damaged vehicles at the unit or organizational level effectively terminated the authorization to stock any Class IX repair parts in the PLL inventory. These

two decisions removed all inventory from combat ASLs and PLLs that was justified in anticipation of use to repair combat damage. Thus, Table 5, circa 1983, contains only FFI, FFII, and FFIII.

In the Fall of 1983, the commander of the U.S. Army Tank-Automotive Command (TACOM) asked for a review of the plans to store combat damage related Class IX repair parts in War Reserve Stocks. A scientific methodology had not been devised to determine the repair part requirements for combat damage, nor was one available from prior practice, if it ever existed. At that time no repair parts were being stored in War Reserve Stocks for the purpose of replacing Class IX repair parts expected to be damaged as a result of combat (Butler & Bain, 1987; Steiner, 1989).

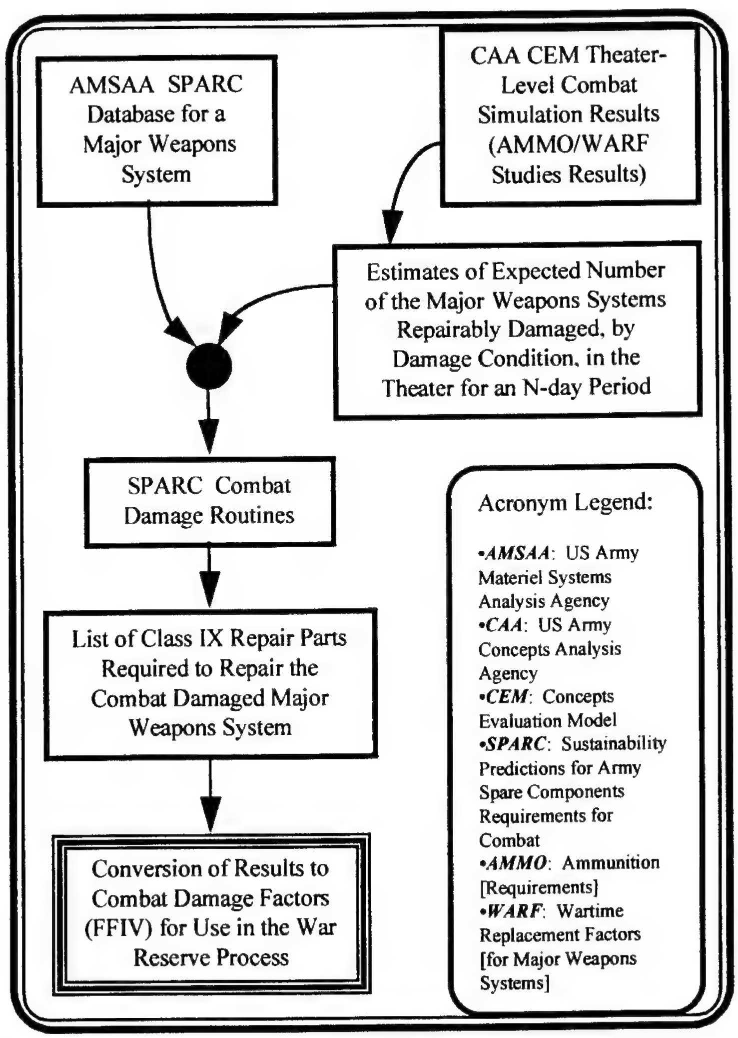

Figure 8: Failure Factor IV Methodology

In response to that situation, Butler & Bain (1987) devised the

methodology outlined in Figure 8 for estimating the damage (and therefore demand) rates for individual repair parts on a specific combat weapons system due to combat. They called their estimate Failure Factor IV (FFIV) and represented it in the same mathematical units as FFI, FFII, and FFIII.

Butler and Bain's methodology derived FFIV from data that were already being acquired for other purposes in separate Army organizations.

1. SPARC. The Sustainability Predictions for Army Spare Components Required for Combat (SPARC) analysis of a specific weapons system is a labor intensive undertaking designed to identify the vulnerability of major weapons systems to the effects of enemy weapons used against them in specific battlefield environments. SPARC analyses are based on direct ballistic effects. Using intelligence information concerning potential enemy weapons and possible engagement situations, the U.S. Army Matériel System Analysis Activity (AMSAA) Ballistics Research Laboratory selects the most likely engagements of enemy weapons for the major weapons system under study. Each type of engagement is then analyzed using computer graphics techniques, component drawings, available empirical data from live-fire exercises, and other relevant information to determine the vulnerability of the major weapons system to each threat engagement type. This is referred to as "shot line analysis" in some literature (Srull, Simms, & Schaible, 1989, p. B-23). The level of detail of SPARC analyses was increased as a result of Butler and Bain's requirement to have information about each individual repair part that

was damaged in the engagement scenario as opposed to the overall vulnerability of the major weapons system.

SPARC analysis does have limitations. No secondary damages are estimated, such as shock damage from the impact of a nonpenetrating projectile, fires resulting from severed electrical cables, warping of the weapons system making repairs more difficult, secondary explosions of fuel or ammunition, or other cascading collateral damage that may follow from the primary weapon effects (Butler & Bain, 1987; Lemire 1993; Srull, Simms, & Schaible, 1989).

Quantifying these secondary effects appears to be extremely complicated. Studies addressing evaluation of these limitations were not found in the literature. However, one may observe that the absence of these considerations would tend to bias the results based on SPARC methodology in favor of the supply system by causing fewer part failures to be predicted than actually would occur. The magnitude, and therefore the significance, of this bias remains unknown.

2. CEM. The U.S. Army Concepts Analysis Agency (CAA) maintains the Concept Evaluation Model (CEM). CEM is a theater-level combat simulation model used on a regular basis to determine ammunition and fuel requirements as well as combat attrition of major weapons systems. CEM is a

deterministic model[7]. Butler and Bain (1987) devised a method "to derive estimates of the expected number of reparable combat damage incidents involving a particular MIE [major weapons system] that are recovered from the battlefield, by conditions at the time of damage, in the theater for the time period of interest."

The results of SPARC and CEM analyses are then combined using Butler and Bain's methodology to calculate FFIV for each repair part receiving damage on the major weapons system being analyzed.

In a related work, Steiner (1989) developed the total quantity of combat failures for the top ten critical anticipated combat damage repair parts for three major weapons systems in a Cold War–era Korean scenario. The methodology parallels the original work of Butler and Bain--Butler is acknowledged as assisting--but stops short of defining Failure Factor IV. Using SPARC data from 1984, and reliability data from 1988, Steiner demonstrated a methodology that "may be used to identify the most frequently [combat] damaged parts of fighting systems for the Korean theater" (Steiner, 1989).

[7] Johnson (1993) reported on a prototype Stochastic Concepts Evaluation Model-Phase III (STOCEM-3) designed to develop theater attrition rates using stochastic modeling methods. Significant differences between CEM and STOCEM-3 measures of interest were observed and further research into possible STOCEM-3 methodologies was recommended.

VII. Battle Damage Assessment and Repair

Concurrently with Butler and Bain's work on FFIV methodology, another initiative, Battle Damage Assessment and Repair (BDAR), was being studied in another Army organization. It is interesting to note that the first BDAR technical manual which describes methods for makeshift battlefield repairs was published in 1984 (Technical, 1984)--less than a year after the stockage of repair parts to remedy combat damage were effectively removed from combat PLL and ASL inventories. In January 1989, the U.S. Army also upgraded its status from observer to participant in the NATO Military Agency for Standardization Army Board Working Party on Battlefield Recovery (Srull, Simms, & Schaible, 1989, p. B-8). BDAR live-fire trials have been held annually at Meppen, Germany, since 1981 with U.S. Army participation beginning in 1986 (Lemire, 1993, pp. 19, 23). At these trials major weapons systems are subjected to the effects of the detonation or impact of actual and representative threat weapons. After these live-fire "attacks" the weapons systems are evaluated for BDAR methods. A collateral benefit of the live-fire BDAR trials at Meppen is that the empirical data produced have been obtained by the AMSAA Ballistics Research Laboratory and used to enhance the accuracy of SPARC.

Although BDAR was not considered to be an important contributor to weapons system readiness during the Persian Gulf War (Lemire, 1993, p. 20), both the BDAR and the FFIV investigations previously described directly

highlight the need to consider failures of parts due to combat damage and the importance of these Class IX repair part inventories to the materiel readiness of weapons systems during combat.

VIII. Logistics Studies and Modeling

Logistics modeling encompasses a broad subject area. In its most comprehensive sense, logistics includes those aspects of military operations concerning ". . . design and development, acquisition, storage, movement, distribution, maintenance, evacuation, and disposition of matériel . . ." (FM 101-5-1, p. 1-43, 1985). In general, the logistics models in the literature are narrowly focused on the dynamics of a specific portion of the logistics spectrum. Inputs to the models generally are deterministic and users are encouraged to do sensitivity and "what if" model runs by changing input parameters. Models of surge capacity[8] of the industrial base typically focus on the physical plants used by prime contractors of major weapons systems and the obvious long lead time items. The underlying subcontractor base is not explicitly modeled and therefore is implicitly assumed to produce components adequately as the prime contractors facilities require them. Several industrial base models are described in the record of proceedings of the Office of Technology Assessment Defense Industrial Base Workshop held in July 1991 (U.S. Congress, 1991, Table B-1, p. 116). These models are also high-level or macro-focused models that deal in terms not lower than major weapons systems. For the most part they are designed to address the past realities represented by the Soviet Union and the Warsaw Pact. Individual components

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[8]Surge capacity during the Cold War was generally measured as the time required to double production quantities. Recently surge has referred to the ability to meet contingency demands.

or repair parts of weapons systems are not considered.

Much attention has been given to the size of the war reserve stock and the development of the economic order quantity for purchasing supplies. The objective and actual levels[9] of the war reserve stocks are of interest. In August 1990, the U.S. Army standard model for determining safety levels and economic order quantities was revised for the first time since 1974 (Kaplan, 1990). Since that time, other inventory models have been suggested to address the decline in U.S. military force structure and thus the decline in supply demands (Bilikam, 1993; Robillard, 1994). Most recently, the clamor has been for the reduction of stockage levels in such ways that the authors claim will cause small but acceptable increases in the probability of critical repair part non-availability (Syzdek, 1994; Army, 1994).

The U.S. Army Matériel Command commissions independent "sector studies" from time to time to evaluate the industrial base. In these sector studies, the participants attempt to identify and propose solutions to avoid or mitigate industrial base weaknesses. A recent sector study of interest to this research is the Tracked and Wheeled Vehicles Industrial Sector Study completed April 28, 1992 (Decker, Aquino, & Napier, 1992). This study is a superb source of information. It includes information about topics such as the identity of vendors of critical components, projected vendor production lead

[9]Objective levels are the level of stockage that are requested by the armed services. The actual stockage level is the quantity available as a result of Congressional authorization.

times, the projected status of the tracked and wheeled vehicle programs, and related industrial base topics. Concern for the health of the industrial base is expressed, and some alternative solutions--generally slanted toward keeping a warm source of supply--are presented. However, no modeling is performed to support recommendations.

Currently, the U.S. Army Concepts Analysis Agency is performing a Theater Capabilities Assessment Study to address the Southwest Asia contingency (Theater, 1994). This study is being performed to obtain answers to logistics questions for the Operations and Plans Division, Army Deputy Chief of Staff for Logistics. In this study, the detailed question of how U.S. forces can be deployed into Southwest Asia to meet the requirements of the Time Phased Force Deployment List (TPFDL)--commonly pronounced "tip fiddle"-- is being examined. A TPFDL contains the sequence and timing of arrival for each unit deploying to a theater with specific airlift or sealift locations (Lund, Berg, & Replogle, 1993, p. 24). The coordination of transportation for combat forces and their required supplies is a primary goal. As previously noted, transportation of forces and supplies is a critical link in successful rapid deployment of a predominantly continental-U.S.-based Army. The industrial base is not explicitly addressed in the Theater Capabilities Assessment Study. Here again the availability of repair parts and supplies is a silent, implicit assumption.

Two models designed for execution on a personal computer in the

literature do explicitly attempt to optimize the distribution of financial resources between war reserve stock inventories and industrial base capacities. The older model is a "D-to-P Spreadsheet Model" developed by Richanbach and Bicksler (1986) using a MacIntosh computer and Excel spreadsheet software. The D-to-P Spreadsheet Model, although no longer in use at the Institute for Defense Analysis, does provide a good tutorial on the types of information required to accomplish inventory versus industrial capacity studies. The more recent model is the Production Expansion/Acceleration Capability Enhancement (PEACE) program developed by the Logistics Management Institute (Culosi & Garner, 1992; Garner et al., 1992, pp. IV-2-2). The PEACE model is deterministic. It is used to analyze a single item of interest (part, major component, ammunition, major end item). The user inputs data defining combat demands, industrial capacity, funding profiles, etc. Warning periods of up to 24 months for industrial base mobilization may be assumed. Three independent major regional conflict demand profiles may be entered with separate start dates. This information is then analyzed by the PEACE model to meet the required demand profile for the item under analysis at minimum costs. Even as a prototype, the PEACE model is easy to use. Data input, program operation, and program output are graphical. Development of the PEACE program ended with version 1.4 published in March 1992.

Unfortunately, no allowance for the true stochastic nature of the phenomena being used as input to the PEACE model is involved. Users of

expected value models must be extremely cautious concerning the use of modeling outputs. The underlying variances of the distributions that have contributed to the expected values used as model inputs are masked and thus the variances of possible--and perhaps unacceptable--outputs are also masked.

The Army Industrial Base Assessment Model (TAIBAM) is an interesting econometric model of the U.S. industrial base. TAIBAM is being developed by Science Applications International Corporation (SAIC) to help the Army Staff translate policy decisions at Department of the Army level into predictions of impacts on resulting theater level battlefields. TAIBAM addresses Army tank-automotive and aviation weapons systems. The breadth of information acquired by SAIC for use in TAIBAM merits its mention as a repository of bibliographic information concerning the industrial base supporting major Army weapons systems (Blackwell, 1994).

An interesting model currently under development by AMSAA is the Optimum Stockage Requirements Analysis Program (OSRAP). OSRAP is a demonstration model designed in an attempt to compute optimum repair part stockage inventories based on combat and reliability-based Class IX repair part demand. PLL and ASL inventories are calculated as single aggregate entities at the major regional conflict (theater) level. Given appropriate resources, the OSRAP methodology could potentially be developed as an effective alternative to the conundrum that is Class IX repair part inventory and

production policy today (Evering & Kwon, 1994).

IX. Class IX Repair Parts and the Persian Gulf War

Some potentially significant implications of agile manufacturing on the defense industrial base have been presented. Yet, one may question whether or not a critical examination of the industrial base supplying Class IX repair parts--as opposed to major weapons systems and their obvious long lead time components--is relevant. The totally successful execution of the Persian Gulf War and the popular press accounts of the mountains of ammunition, food and matériel stocks to be returned to the U.S. after the war may lead some observers to assume by extrapolation that the supply of Class IX repair parts was evidently adequate as well.

A review of the post–Persian Gulf War literature does not support that conclusion. During the Persian Gulf War there were looming shortages in everything from batteries to ammunition (Melius, 1991; Mazarr, Snider, & Blackwell, 1993). It is especially enlightening to learn that almost $105 million worth of parts in inventory for scheduled Abrams Main Battle Tank production at General Dynamics Land Systems had to be diverted to meet the repair part demands of U.S. Army forces in Saudi Arabia. These parts "ranged from high dollar engines, transmissions, gunner's primary sights, thermal receiver units, numerous electronic boxes, to final drives and road wheels" (Decker, Aquino, & Napier, 1992, Part I, p. 14). After conducting a detailed supply analysis, Correll and Nash (1991) conclude that (1) the brevity of the Persian Gulf War concealed potentially disastrous inadequacies in the industrial base and (2)

that there was no "surge" only a "speedup" of production in support of the war (Correll & Nash, 1991).

During the Persian Gulf War a total of 3,113 Abrams tanks were deployed to the Persian Gulf area. Of these, 2,024 tanks were assigned to deployed military units. The balance of 1,089 tanks were kept as reserve. The 2,024 Abrams consisted of 1,904 M1A1 and 120 M1 series tanks. Although the Abrams maintained an operational readiness rate of over 90% during the 100-hour ground war, ". . . Abrams crews reported problems obtaining repair parts, and many had exhausted their limited supply of some parts by the end of the ground war. . . . sustainability could have become a major problem had the war lasted longer [than 100 hours]" (GAO, 1992, January). It generally appears that the PLL quantities of repair parts authorized for combat tank battalions were inadequate to support the actual demand experienced during combat.

Some have argued that adequate stocks of most needed Class IX repair parts were actually available in the Persian Gulf Theater and that the distribution of these parts was simply inadequate. Even if this argument is valid, the fact that the 15-day PLL supplies did not last through the 100-hour ground war is unacceptable and requires investigation.

In light of these revelations about the actual state of supply availability during the Persian Gulf War, the need for a quantitative analysis of the requirements for Class IX repair parts and the implied production parameters

that these requirements place on an agile or nonagile manufacturing industrial base becomes crystal clear.

X. Procurement Holiday Effects

> ***"The Army sadly has no modernization program to speak of"***
>
> -John Hamre, DOD Comptroller, 26 April 1995

"The Army sadly has no modernization program to speak of, " John Hamre, the Department of Defense Comptroller, said at a Defense Budget Project conference on April 26, 1995. With the exception of the Army digitization program funding levels, Hamre termed the recent years' Army research, development and acquisition budgets as "fairly anemic" (Adelsberger, 1995).

When faced with the reality of a rapid decrease in total budgets in 1990, the Army initially sacrificed research, development, and acquisition funds in favor of maintaining the near-term operational readiness of the existing force structure (Austin, 1994, p. 29). This decision can be understood in the context of the Persian Gulf War and the very real potential for hostility that Iraq has maintained after that conflict. In recent years, the Army leadership has gradually become concerned that the existing armor and aviation weapons systems could become outdated by the next decade unless additional modernization funds are made available. The Chief of Staff of the Army, General Gordon Sullivan, testified to Congress that the Army needed $14 billion annually to modernize weapons and equipment adequately (Tice, 1995). Current [1995] modernization budgets are approximately $10 billion annually.

This view was underscored at DOD by the budget planning guidance for

FY97 and beyond issued by Defense Secretary William Perry in April 1995. In his budget planning guidance, Secretary Perry mandates a 475,000-soldier Army by 1998, a 20,000-soldier reduction below the Bottom Up Review target of a 495,000-soldier Army. The money saved by this additional personnel reduction would allow an increase, \$1.6 billion in FY97 and \$1.1 billion in FY98, in Army research, development, and acquisition funding (Adelsberger, 1995). Recent U.S. Army budget information is shown in Figure 9 and Table 6.

Army research, development and acquisition accounts have been reduced over 50 percent from the levels of the 1980s. In response to this approximate \$15 billion reduction (Tice, 1995) of annual market potential, defense contractors at all levels are leaving the defense market. Some sell their defense divisions to other companies that are consolidating to maintain profit margins in the defense sector, some convert to civilian production, and others go out of business. Many firms have indicated that once they leave the defense market, they will not return (Decker, Aquino, & Napier, 1992; Ray & Morris, 1994; Scivally, Franklin, & McPeak, 1994; Skibbie, 1994; Industrial, 1992). As Clem reminded us a decade ago, in our free enterprise system:

> *There exists in reality no separate, captive defense industrial base. Rather, one is dealing for the most part here with the complex, dynamic, and interdependent world of the commercial marketplace where anticipated profits are the primary motivating force behind responsiveness and change.* (Clem, 1983, p. 113)

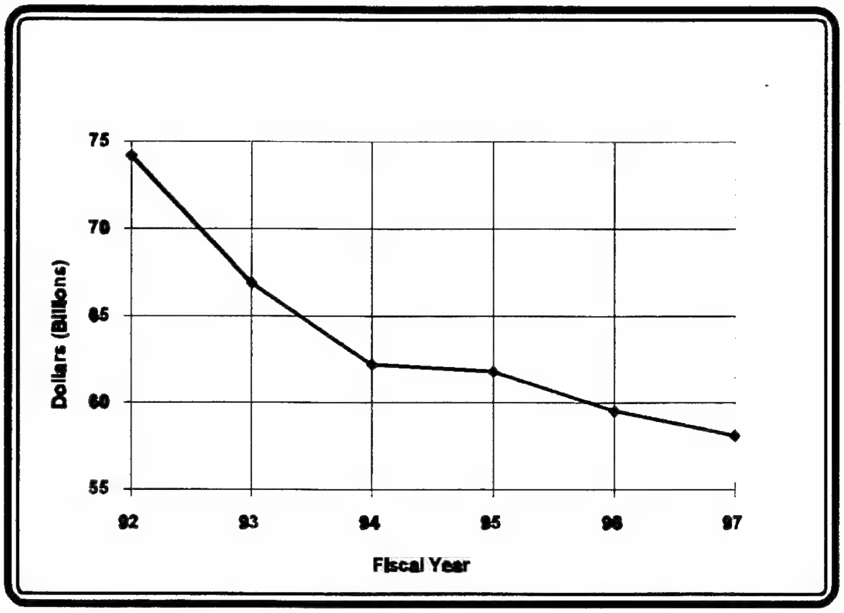


Figure 9: Total Army Budgets FY92 to FY97

Table 6: Army Budget Allocations

Army Appropriation (Fiscal Year in $ Billions)	FY95	FY96	FY97 (est)
Military Personnel	26.1	25.0	24.7
Operations & Maintenance	21.2	20.6	20.9
Procurement	6.9	6.3	5.9
Research & Development	5.5	5.5	4.2
Military Construction	0.8	0.8	0.6
Family Housing	1.2	1.2	1.4
Base Closure	0.1	0.3	0.3
TOTAL	61.8	59.5	58.1

In the instances where a major weapons system goes out of production, the only market remaining is for repair parts. The relative predictability of production demand with a variable repair part component superimposed is ending as production lines shut down in the 1990s. Therefore, the previously masked, lower-tier producers of repair parts for the major prime contractors and major subcontractors are steadily being elevated to the level of first-tier repair part provider. The reduction in the active duty army force structure serves to increase uncertainty and to exacerbate defense firms' assessments of future repair part demands. At some point, the utility of competing in alternative markets will be greater than the utility for these firms to remain as repair part vendors for military weapons systems.

An example of this phenomenon from the tank-automotive industrial sector is the U.S. Army's Abrams Main Battle Tank. Production of the Abrams M1A2 model at the Lima Army Tank Plant ceases in 1995. When production ceases, the market for Abrams repair parts will consist of demands to support the existing U.S. Army fleet of approximately 2,783 M1s and M1IPs, 4460 M1A1s and 194 M1A2s (Miller, 1994), foreign sales, and the requirements to support for a minimum conversion program of M1 Abrams to M1A2 Abrams. The Army initially sought to convert 240 Abrams per.year, cut that number to 120 per year, and may realize funds for only 100 Abrams conversions in FY96 and 90 conversions annually thereafter (Glashow, 1995). Abrams production is a market in which over 10,000 firms of all sizes participate. Over 650

vendors directly support the prime contractor, General Dynamics Land Systems (GDLS). Some 15% of these 650 vendors are small businesses for whom GDLS is their sole customer, and 30% of these vendors do 50% of their business with GDLS. Many of these firms intend to depart the defense sector after Abrams production is halted (Industrial, 1992). It is feared by some that the end of active Abrams production will mark the beginning of an era in which "many critical defense suppliers [for the Abrams] are expected to go cold; the capability to create spare parts will be lost; and linkage between technology and production will be in jeopardy" (Ray & Morris, 1994).

XI. Assault on Inventories

As a whole, the DOD spends approximately $64 billion annually on its logistics system. The overall logistics system is bound by regulations that often prohibit the implementation of commercially proven, efficient methods. The management of inventories is done with 1970s computers and software systems which do not provide "accurate figures" concerning cost, inventories, and expenditures (Matthews, 1995). These circumstances make the military logistics system an easy target for criticism.

The Army is already being pressured to reduce the inventory of repair parts at all levels of supply from the unit PLL to War Reserve Stocks. The General Accounting Office (GAO) has admonished the Army to only stock <u>demand</u> <u>supported</u> Class IX repair parts in PLL and ASL inventories. The GAO proposes that all repair parts, including mandatory stockage parts and command-directed stockage parts, should be disallowed if they are not demand-supported. Noting that a large number of the repair parts maintained in PLL and ASL inventories "contribute little" to the supported weapons systems' operational readiness based on the number of demands, the GAO further suggests that the criterion for authorizing stockage of a repair part be raised from three demands in a one-year period to as many as twelve demands in a one-year period to qualify for continued ASL stockage. No allowance for combat demands is considered. The GAO report continues:

Stocking items at the retail level that receive few demands

> *represents an inventory investment that could be avoided. As we previously reported, these items could be deleted from the [Army combat] divisions' authorized inventory; relocated to the wholesale level depots, and issued to the units as needed. Doing so would not impair supply responsiveness because (1) many of the items had no demands and (2) only about 8 percent of the items demanded were for items considered mission essential--meaning that nonavailability of the item could impact on a unit's mission capability. Additionally, with the advancements in transportation, such as overnight delivery, and expedited processing at the storage depots, the nonavailability of such a small number of items at the division level should not significantly affect the ability of the units to accomplish their training mission* (ARMY, 1994).

While ultimately logical for a relatively stable peacetime environment, recommendations of this nature defy the reality of the rapid reaction requirements that major regional conflicts represent and, as this study will reveal, could result in a significant reduction in the operational availability of major weapons systems committed to regional contingency combat operations. While it is certainly true that overnight express services can deliver most sizes and shapes of repair parts around the world in 24 to 48 hours, these deliveries are not routinely made to combat zones. After Iraq used SCUD tactical ballistic missiles in the Persian Gulf War, the pilots of commercial aircraft flying as part of the Civil Reserve Aircraft Fleet (CRAF), were restricted from flying into Saudi Arabia during the hours of darkness by their parent companies. This restriction was based on the potential--but never used--capability of Iraqi SCUD missiles to deliver lethal, and perhaps persistent, chemical nerve agents to the Saudi airports of debarkation. Civilian aircraft are not equipped

for use in a nuclear, biological, or chemical environments. Fortunately, the Iraqi military was limited by allied air superiority to using SCUD missiles at night. Commercial contract air carriers similarly restricted their aircraft operations in the Southwest Asia Theater. (Lund, Berg, & Replogle, 1993, pp. 28-29). In addition, if the combination of real time production and existing inventories is insufficient to meet the spike in repair part demands that the weapons systems in two nearly simultaneous regional contingencies will generate, a rapid transportation capability will not mitigate a lack of parts.

One improvement that will assist logisticians to more effectively manage repair parts already in the Army supply system is under development. It is the Total Asset Visibility (TAV) system which is intended to provide daily worldwide visibility of repair part inventory status by national stock number and location. TAV was a direct response to the difficulties experienced during the Persian Gulf War of locating available stocks of repair parts after they were delivered into the combat theater. Access to TAV will be available via the Internet or by direct dial-up using a PC and modem when the development is complete. The questions of "where, what condition, and how many" concerning individual Class IX repair parts in the U.S. Army supply system are being addressed with the development of TAV.

The assault on inventories can only be anticipated to gain momentum as commercial industry demonstrates the advantages of agile manufacturing and reaps the benefits of lower inventory costs. Fiscal pressures on the War

Reserve line in the defense budget and outside pressures from agencies such as the GAO on the Army to reduce the expense of inventories will have an effect. Agile manufacturing may provide the means for the Army to avoid the high costs of purchasing and maintaining inventory while providing the required capacity to meet repair part demands during peacetime and wartime.

XII. Operational Readiness Calculations

A general calculation for the operational availability, A_o, of a major weapons system is shown in Figure 10 (Acquisition, 1995, p. II-11). This

$$A_o = \frac{OT + ST}{OT + ST + TCM + TPM + TALDT}$$

LEGEND:

A_o:	Operational Availability
OT:	Operating Time
ST:	Standby Time
TCM:	Total Corrective Maintenance Time (unscheduled) per time period
TPM:	Total Preventive Maintenance Time (scheduled) per time period
TALDT:	Total Administrative and Logistics Down Time spent awaiting parts, maintenance personnel, or transportation per time period

Figure 10: Operational Availability Equation

equation dictates that the logical objective of the Class IX repair parts authorized for stockage as PLL and ASL inventories is to minimize the proportion of total administrative and logistics time that is spent awaiting repair parts. The time that a weapons system remains non-operational due to lack of required repair parts is known as "not mission capable (due to) supply" (NMCS) time.

In practice A_o is calculated by surveying the operational status of all assigned weapons systems once during every 24 hour period. Therefore, if a

repair part is needed to repair a weapons system, the part is available, and it is installed prior to the end of the 24 hour, the weapons system is counted as available. A_o is a component of the operational readiness statistics reported by all U.S. Army combat units as required in Army Regulation 220-1: Unit Status Reporting (1993). Daily A_o calculations are consolidated for monthly and quarterly reports which are classified for security reasons and not available to the general public. Each major weapons system type has an established operational availability goal. Typical minimum operational availability goals are 90% for tank-automotive weapons systems and 75% for aviation weapons systems.

XIII. Problem Definition

The temporal coupling of the reduction in the U.S. Army budget and force structure and the identification and manifestation of agile manufacturing in the industrial base raises some interesting questions and possibilities. Future Class IX repair part planning and policy decisions must include the alternative of agile manufacturing in the important balance between financing industrial capacity and purchasing and maintaining inventory. Past industrial base modeling addressed the production of major weapons systems. Future major regional conflicts are anticipated to begin and end within six months and be fought essentially with the major weapons systems available at the start of hostilities. The Department of Defense "procurement holiday" manifests itself as "Army weapons systems in current production are being slowed, reduced, or curtailed while future new major weapons system production is pushed further and further into the latter part of the next decade" (Naylor, 1994, p 13).

Agile manufacturing represents new possibilities in the production responsiveness of industry which can directly impact the matériel readiness of U.S. Army weapons systems. If, as Zeller (1991) imagined and the Defense Science Board foreshadowed in describing integrated process and product development, an agilized industrial base makes it feasible to consider producing battlefield demands for parts on a real time produce-on-demand basis, what production profiles are required? Given the sheer quantity of weapons systems and their multitude of repair parts, the need arises for a

quick and uncomplicated procedure to quantify the expected demand for each of the repair parts that are components of a major weapons system. Then given the demand, how can alternative combinations of inventory and industrial capacity posed as logistics repair part policies be evaluated and compared?

XIV. Modeling Methodology Objectives

A. Objectives. To answer these questions, we propose a general stochastic modeling methodology. The methodology encompasses these two related objectives which may be accomplished in a given scenario containing a maximum of two major simultaneous regional conflicts:

> **Objective 1:** Parametrically quantify the daily requirements for all Class IX repair parts for an individual major weapons system during the scenario.
>
> **Objective 2:** Compare the operational readiness of the major weapons system resulting from alternative combinations of repair part inventory and industrial production capacity during the scenario.

B. Modeling Bias. Bias is an inherent factor that must be resolved in all simulations and models. Because we desire to calculate a minimum or lower bound of the expected daily quantity of repair part failures, we bias the model in favor of the success of the U.S. Army supply system. In this way, the predictions of supply system performance, and thus production requirements generated in this methodology constitute a lower bound. Bias has consciously been introduced in the simulation model in these ways:

1. When determining the quantity of repair part failures expected in the scenario for Objective 1, all Abrams tanks are assumed to be operational at the start of each day. This forces the daily repair part failures to be based on the optimum quantity of tanks in the scenario.

2. Tank units that are deployed to Southwest Asia and Northeast Asia

are assigned a daily combat status of reserve, reduced, moderate, or intense. In the scenarios provided, the combat status is listed in ten- and five-day blocks, with the exact order of these assignments within each block unspecified. The initial status of units upon arrival in Northeast Asia or Southwest Asia is usually reserve. Discussions with subject matter experts indicated that it is most appropriate to order the higher intensity of combat first within each block to model a cycle of preparation for combat while in reserve, movement to combat, and then preparation for more intense combat again. The impact of this decision is to place the highest repair part failure rate for each tank unit up to ten days earlier in the chronology than would be calculated if the order of combat intensities were ordered from least to greatest. Regardless of the internal ordering of combat intensities within each ten- or five-day period, the cumulative quantity of failures resulting from the model for Objective 1 purposes would have the same expected value at the end of each of those periods. While a strictly minimum repair part failure quantity could have been generated by arbitrary ordering of combat intensities from lower to higher, the resolution chosen is closer to the way that the scenario is anticipated to unfold on the battlefield.

3. Repair parts that are created via manufacturing or exist in initial inventory are not subjected to attrition. Therefore, no additional repair part requirements are generated to replace damaged, lost, destroyed, or otherwise not available repair parts in the model.

4. Total Asset Visibility is assumed to be operational and used by logistics personnel at every level to direct available repair parts to the subordinate inventory location which has the lowest percentage of authorized stocks. This logic is applied at all levels of repair part inventories beginning with the decision of which theater to send available repair parts when they depart the continental U.S.

5. All combat units which are not scheduled to deploy to a major regional conflict are assumed to continue to experience repair part failures at the same rate as during peacetime, i.e. FFI. The bias is in the favor of the supply system, because soldiers tend to look a bit more closely at their equipment when a conflict breaks out whether or not they are scheduled to deploy. The actual use of some repair parts in this situation will be larger than in peacetime.

6. Transportation of repair parts between all points in the simulation is deterministic. All modes of transportation available in the model are always available when needed, and always deliver the repair parts to their destination.

7. All units assigned to a major regional contingency arrive with all of their major weapons systems and supporting repair part inventories as scheduled in the scenario. There are no transportation delays or losses.

XV. Repair Part Requirements Quantification

Promoters of agile manufacturing would lead the casual observer to assume that the coming agile industrial base will be able to respond to demands somewhat like a household water faucet: just turn it on when needed. But even under the most optimistic agile manufacturing conditions, the production of repair parts cannot be turned on like water from a faucet unless the "agilized repair part manufacturer," or the more generalized agile manufacturing industrial base, has the total capacity required perpetually resident and immediately available to assign to repair part manufacturing at the required rate of production. This production capacity, if it were to exist in an agilized manufacturer, would exist because there was an economic incentive motivating the manufacturer to maintain that capacity. Transportation from the manufacturer to the combat user would also have to be perpetually available and timely for a production based military supply plan to be credible.

The first task in the methodology is to generate daily repair part requirements for a particular Class IX repair part for a particular major weapons system at the battalion level. These daily requirements for each battalion in a particular conflict region or theater are then summed to create a demand profile for the part that would be expected to be experienced on the particular major weapons system for the theater in the scenario. The demand profiles for all combat theaters are then aggregated with the demands from units not scheduled to deploy to a combat theater to create a total daily

demand profile for the repair part for the major weapons system fleet. By executing multiple iterations of the simulation model, a confidence interval and prediction interval around the daily mean part requirement can be generated. If the part is used on multiple weapons systems, the demand curves for the part for all of those weapons systems may be aggregated to obtain the total expected daily demand curve. A demand profile or curve computed in this manner defines the minimum performance requirements against which all postulated combinations of inventory and production capacities in alternative repair part policies can measure their success.

Unfortunately, the effort required to calculate an individual demand curve for each Class IX repair part which is a component of each major weapons system as just described would be impractical due to the sheer quantity of individual repair parts and weapons systems in the Army inventory.

However, by observing that the failure factors for repair parts for a specific weapons system have minimum and maximum values that fall within finite ranges, one can generate a family of notional parts with failure factor profiles which span the range of the actual individual repair part failure factor profiles. This idea is similar to creating a mesh in a mechanics of materials finite element analysis. Having designed an appropriate mesh of failure factor profiles, a family of daily repair part failure curves is generated using the simulation model. Due to the design of the mesh of failure factor profiles, actual failure factors for each part on a weapons system will then fall between

two of the failure factor profiles generated. The demand profile of the actual part is then bounded between the demand profiles of the two representative parts. By comparing an actual failure factor profile to the mesh of failure factor profiles generated, a bounded range of demands for the actual part can be rapidly determined. This method allows rapid daily estimates of the number of failures of all individual repair parts for a major weapons system in a previously modeled scenario without subsequent recourse to the simulation. The daily failures of any repair part can be determined as a simple function of the failure factors for any repair part of interest on the weapons system of interest.

Because each scenario, such as Southwest Asia and Northeast Asia, is independent of the others in terms of part failures, individual scenarios modeled and analyzed using this method may be superimposed over each other to assess cumulative part failures in separate or simultaneous conflicts over a given time horizon. In this manner, the daily quantity of individual repair part failures can be projected for any combination of given scenarios and time horizons without extended effort. These daily individual part failure profiles represent the minimum daily production required of an "agilized" repair part manufacturer producing repair parts on demand for delivery to the battlefield user. Of course there must be an allowance for an initial inventory of repair parts to avoid "stock out" situations while newly demanded and produced parts are routed to their battlefield destinations. The design of the failure factor mesh involves classic tradeoffs between the fidelity of results and the expense

of producing those results: the finer the mesh the smaller the range between adjacent resulting demand curves, but a fine mesh contains more representative repair parts to simulate; the larger the mesh the larger the range between adjacent resulting demand curves, but a larger mesh contains fewer representative repair parts to simulate. The granularity of the bounds for real demand estimates using this method is a function of the size of the failure factor mesh used to define the representative family of repair parts.

As a minimum, the family of representative repair part failures generated using the failure factor mesh can be used to screen repair parts based on their actual failure factor profile. The family of actual repair parts for a major weapons system or common to multiple weapons systems can be stratified for relative levels of management based on the results of the representative part analyses.

The discussion of representative repair parts and failure factor meshes does not preclude the use of this methodology to analyze actual repair part failure factors. This explicit use would be prudent for situations in which more accurate data than the bounds provided by the representative repair parts provide is required.

A complete demonstration of the modeling methodology developed to accomplish these objectives is presented for the most stressing Bottom Up Review scenario: the nearly simultaneous Northeast Asia and Southwest Asia major regional conflict scenarios.

XVI. Weapons System for Analysis

The M1 Series Abrams Main Battle Tank is chosen to be the major weapons system in this demonstration. A drawing of the M1A2 model is included as Figure 11. As previously detailed in Chapter X, the Abrams program has experienced the impacts of a reduced Army budget, and the production of new Abrams M1A2 tanks will end in 1995. As the major armored weapons system in the Army, the importance of the Abrams' operational readiness to the combat effectiveness of the U.S. Army is obvious.

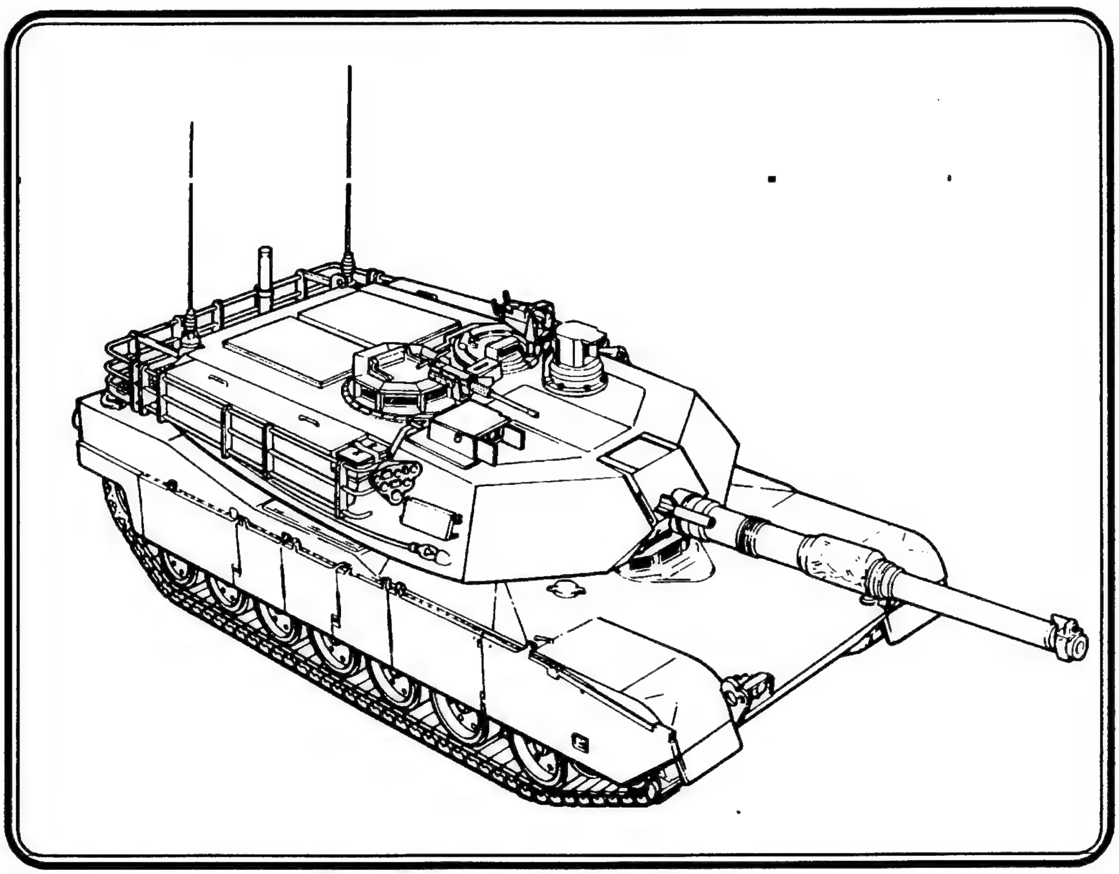


Figure 11: Abrams Main Battle Tank, M1A2 Model

XVII. Scenario

The number and kind of military units with Abrams tanks that are designated to deploy and fight in the Northeast Asia and Southwest Asia scenarios were distilled from Total Army Analysis (TAA) 2001. TAA 2001 is the latest available TAA study produced by the U.S. Army Concepts Analysis Agency (CAA). Periodically CAA uses the Concepts Evaluation Model to justify the need for the Army force structure to perform future missions. Southwest Asia and Northeast Asia scenarios were included in TAA 2001 because these scenarios represent part of the future potential missions for the U.S. Army. All of the scenario data used in this demonstration, such as the number of units scheduled for deployment, time phased deployment schedules, and daily unit combat status, are contained in the database of information for units that are assigned Abrams tanks in the TAA 2001 version of the Southwest Asia and Northeast Asia major regional conflicts.

In our demonstration, the Northeast Asia and Southwest Asia scenarios are analyzed over a 150 day period. [The simulation model provided can support a maximum of 170 consecutive days of analysis.] The Northeast Asia scenario begins on D-day and continues for a duration of 150 days. The Southwest Asia Scenario begins 25 days after D-day for Northeast Asia and continues for a duration of 125 days. Projected combat status conditions for each unit were given in five- and ten-day blocks. The days within each of those blocks were further divided into time spent in intense combat, moderate

combat, reduced combat, or combat reserve. The daily combat status for each tank unit in the Southwest Asia and Northeast Asia scenarios is listed in Appendices C and D. Throughout the model, the highest intensity of combat during each block of days was scheduled first to reflect a cycle of intense activity followed by consolidation of forces in preparation for more intense activities. Both scenarios end and the simulation stops after 150 days. By choosing to start Southwest Asia with a 25-day lag from Northeast Asia, both scenarios are active simultaneously and the minimum requirements for repair parts given the Bottom Up Review projections will be estimated for the worst-case scenario. As previously noted, an analyst may use the information generated in this analysis of anticipated repair part demands to project daily part requirements for all time lag combinations of these Northeast Asia and Southwest Asia scenarios over any chosen time horizon without running the simulation again.

XVIII. Time Phase Force Deployment

Abrams Tanks are assigned to battalions and Armored Cavalry units. In our scenario fourteen tank battalions and one composite Armored Cavalry unit are assigned to Northeast Asia. Twenty-eight tank battalions are assigned to Southwest Asia. Each tank battalion is assigned 70 tanks, the Armored Cavalry composite unit is assigned 148 tanks, and the total Army inventory of Abrams tanks is set to 7,778. A total of 1,960 Abrams tanks are scheduled to deploy to Southwest Asia, 1,128 Abrams are scheduled to deploy to Northeast Asia, and the remainder of 4,690 are not scheduled to deploy to either Southwest Asia or Northeast Asia.

The number of tanks in each tank battalion and the Armored Cavalry unit as well as the total number of Abrams tanks in the Army inventory are notional. Using these numbers allows the demonstration of this methodology while avoiding classification issues as outlined in the preliminaries of this study. All other data obtained from the TAA 2001 for the Northeast Asia and Southwest Asia is authentically represented in the model.

An abbreviated Time Phased Force Deployment List (TPFDL) of each battalion-sized unit, including the composite Armored Cavalry unit, is included as Appendix C for the Northeast Asia scenario, and Appendix D for the Southwest Asia scenario. The daily cumulative number of Abrams tanks in the scenario modeled is shown in Figure 12.

To simplify accounting, the unit designation numbers from the TAA 2001

analysis were maintained in this work with one modification: A "-S" was added as a suffix to the unit identification number for a single battalion with a unique unit designation number and a "-1" or a "-2" was added to the unit designation of those battalion sized units that were consolidated in the TAA 2001 data in order to uniquely identify the two battalions contained in each case. A list of the unit identification numbers used in this model is in Appendix E.

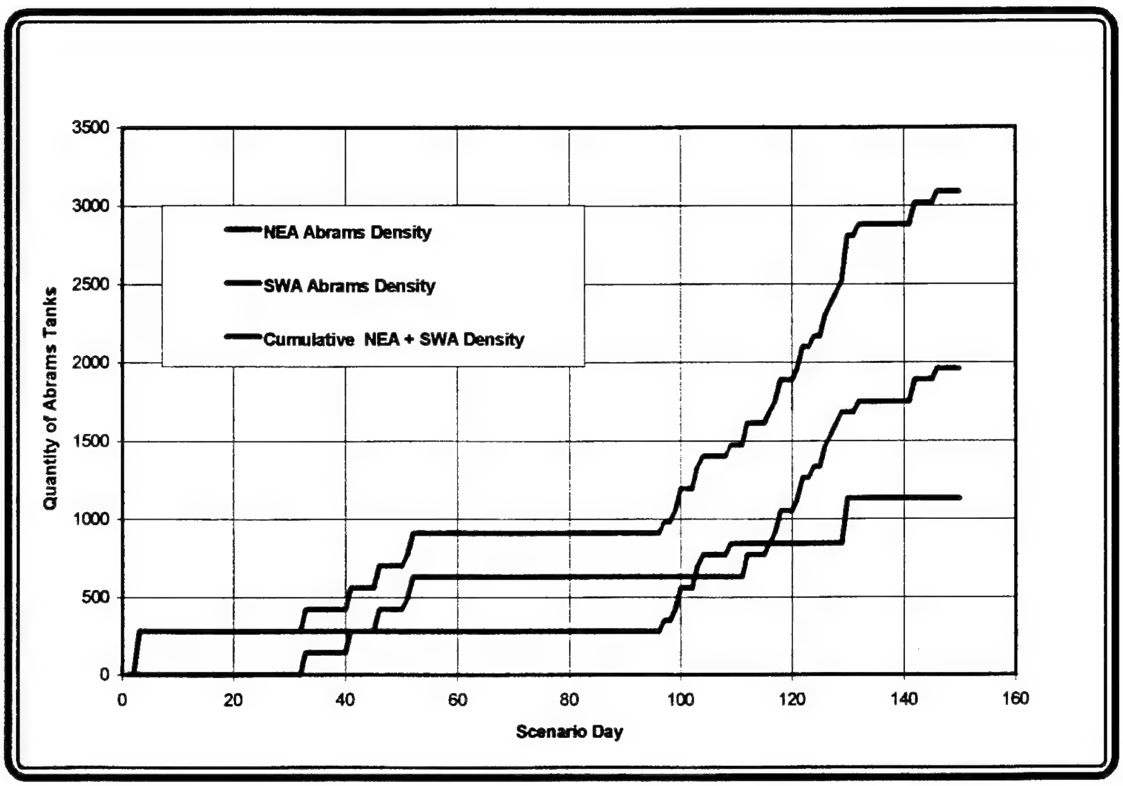


Figure 12: Cumulative Density of Abrams Tanks in NEA and SWA

XIX. Failure Factor Mesh

To determine the failure factor profile mesh to represent the repair parts on the M1A1, available failure factors for 595 parts on the M1A1 Candidate Item File were obtained from AMSAA and TACOM. All failure factors obtained for the 595 parts were then normalized as multiples of FFI. Explicit variations of FFIII are easily accommodated because FFIII is simply used as a multiplier for FFII in theaters with significant environmental factors. When the value of FFIII is not unity for a repair part on weapons systems being assigned to a particular combat theater, the product of FFII and FFIII is used instead of the unadjusted FFII. Subsequently sorting the normalized failure factor data base by FFII, FFIV in Northeast Asia, and FFIV in Southwest Asia revealed the high and low range of these factors as multiples of FFI. The mesh chosen to generate Class IX repair part failure factor profiles is contained in Table 7.

Table 7: Failure Factor Profiles

Failure Factor I	Failure Factor II	Failure Factor IV (NEA)	Failure Factor IV (SWA)
X	X	0X	0X
	2X	.5X	.5X
	3X	X	X
	6X	2X	2X
		5X	5X

This mesh contains a total of 100 unique combinations of failure factors which define 100 unique representative parts for use in the analysis. A subject-matter expert confirmed the resulting ratios of FFI to FFII for Class IX repair parts of weapons systems managed by TACOM as ranging between 1 and 6 times FFI, with the most likely ratio being 1 to 2.5 (Paslaski, 1995). A value of FFI = X = 20 failures/100 tanks/365 days or 0.00548 failures/tank/day was used in the simulation as a baseline to calculate the failure factors for each of the representative repair parts. For repair parts with values of FFI other than X, the simulation results can be scaled by the ratio of $\frac{FF1_{actual}}{20}$. The 100 representative parts and their calculated failure factors are listed in Appendix F.

XX. Simulation

The simulation software used in this demonstration model was SIMFACTORY II.5-SIMPROCESS which is produced and marketed by CACI Products Company, La Jolla, CA (SIMFACTORY, 1994). The model was hosted on an IBM compatible personal computer with a 90Mhz Pentium central processing unit and 16 megabytes of random access memory. The operating system was Windows for Workgroups version 3.11. Source code for determining the daily failures for representative part 100 is included as file "ag100.zip" on a 3.5 inch 1.44 megabyte diskette, labeled "Diskette 1."

A. Model Entities. Icons used in the layout of the simulation are identified in Figure 13. A layout of the icons in the simulation model is provided in Figure 14. In Figure 14 the Northeast Asia Theater is represented in the upper right corner, the Southwest Asia Theater on the left side, the continental U.S. based activities in the lower right corner, and prepositioned stocks located in the middle bottom. The blue circular nodes are pick up and delivery points along the paths where repair parts are transferred between transporters and

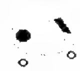
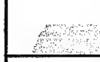
	ASL
	Air Cargo
	Combat Unit
	Prepositioned Ship
	Transporter
	Prepositioned Stock
	Ship, CONUS
	Ports, Vendor
	PLL
	Transporter

Figure 13: Icon Identities

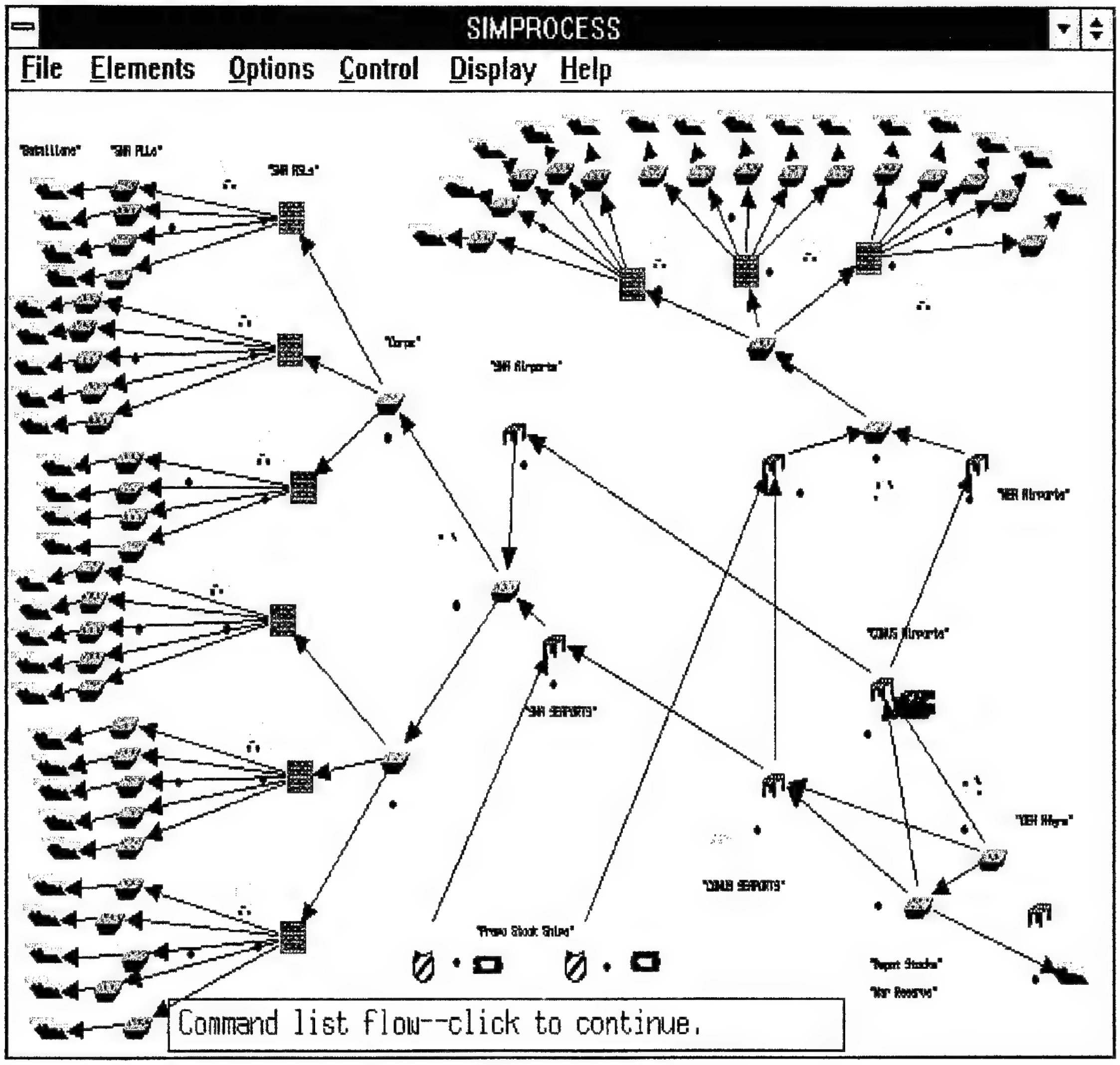


Figure 14: Repair Part Flow to SWA and NEA

storage locations. The blue arrows denote the logical flow of repair parts in the supply system from source to end user on the battlefield.

1. Inventory Locations. Inventory of spare parts can be maintained at storage locations along the repair part flow path. The inventory of spare parts is initialized at each location by setting the attribute "Part 1: Count" to the number of parts desired. The maximum number of repair parts authorized at a location is initialized by setting the attribute "Part 1: Max" to the maximum

number of parts authorized. In traditional analysis, for example, the PLL would be set to an integer value equal to the expected 15-day failures for the number of weapons systems being supported. Once the maximum number of repair parts is stocked in an inventory point, it is blocked from receiving additional parts.

2. Transporters. The transporters fall into five categories: aircraft, ships, Port-to-ASL trucks, CONUS trucks, and ASL-to-combat-unit trucks. The ground transportation between any two locations in the model takes 24 hours. A one-way trip from the continental U.S. to Southwest Asia by aircraft requires approximately 25 hours (Lund, Burg, & Replogle, 1993, p. 32). The total load, fly, and unload time for aircraft is 1.5 days from the continental U.S. to Southwest Asia or Northeast Asia. Ships transporting repair parts from continental U.S. ports to Northeast Asian or Southwest Asian ports require 1.25 days to load, 14 days transit time and 1 day to unload. (Cooley, 1994). Prepositioned ships require a total of 10.25 days from D-day until their inventories are available at Southwest Asian or Northeast Asian ports.

3. Combat Units. The combat battalions and the composite armored cavalry unit are initialized with their authorized number of Abrams tanks in operational status at the beginning of the war. When a part fails, a tank is taken out of operational status until a repair part is available. If a part is available in the PLL, the tank is repaired prior to being counted as non-operational.

4. Manufacturer. The production schedule for any combination of repair part manufacturers may be entered in the model to create any presumed schedule of production for evaluation.

B. Model Logic. As previously noted, the possible flows of repair parts in the scenario are indicated by the blue arrows in Figure 14. The logic that guides parts through a SIMPROCESS model is resident in the parts. Each part follows its "process plan" from location to location. Complete control of the process is accomplished with real time computed conditional branching. The flow is always one way and does not allow for lateral transfers of repair parts among ASLs or PLLs.

1. Part Failures. Failures of the repair part being analyzed on the Abrams tank are segregated by the status of each tank battalion when the failure occurs. The five states of nature for tank battalions in which failure statistics are collected are:

(1) Scheduled for deployment to Northeast Asia (but not yet there)
(2) Deployed in Northeast Asia
(3) Scheduled for deployment to Southwest Asia
(4) Deployed in Southwest Asia
(5) Not Scheduled for deployment to Northeast Asia or Southwest Asia.

These five states are gathered separately because the underlying stochastic mechanisms responsible for them are statistically independent of one another. The segregation of the data in this manner allows the creation of failure curves for any combination of these Northeast Asia and Southwest Asia contingencies

without further simulation.

The simulation proceeds on a time step basis. Each unit of simulation time represents one 24 hour day. The daily failures assessed to each battalion and the armored calvary unit are calculated based on the expected value of the number of failures for each day. The expected value of the number of failures of the repair part is generated by the product:

$$\boxed{E[F_{ijt}] = (N_{jt})(B_{ijt} + \alpha_{jt} C_{ijt})}$$

where

F_{ijt} = Number of failures for part **i** in battalion **j** during day **t**

N_{jt} = Number of operationally ready tanks in battalion **j** at the beginning of day **t**

B_{ijt} = Expected value of RAM based failures of part **i** per tank per day in battalion **j** during day **t**

α_{jt} = Combat status coefficient for battalion **j** during day **t**

C_{ijt} = Expected value of combat related failures of part **i** per tank per day in battalion **j** during day **t**.

The combat status coefficient, α, is a coefficient multiplier for FFIV to adjust for varying levels of combat intensity. For units in reserve, $\alpha = 0$, for reduced combat status $\alpha = 0.8$, for moderate combat status $\alpha = 1.0$ and for intense combat status $\alpha = 1.2$ (Simberg & Evering, 1995). The combat failure factor, **C**, is FFIV for the part in Southwest Asia or Northeast Asia. The base failure factor, **B**, is FFI for units not scheduled to deploy to Southwest Asia or

Northeast Asia, otherwise it is FFII. The assumption is that units scheduled for deployment to Northeast Asia or Southwest Asia will increase their training activities from FFI levels to FFII levels beginning on D-Day of any regional contingency in preparation for possible deployment.

The number of operational tanks in a battalion, **N**, is set to a constant when the model is used in Objective 1 mode to determine the minimum demand profile for the near simultaneous Southwest Asia and Northeast Asia contingencies. In this mode **N** is set to the number of tanks authorized in each unit. In Objective 2 mode the value of **N** is initialized at the authorized number of Abrams tanks and is changed as parts fail and repairs are made as simulation time lapses. Setting the model up for Objective 1 and Objective 2 analyses is provided in Appendix G.

Due to the wide range of independent factors that can influence the actual number of part failures, F, during each period, t, the distribution of F satisfies the requirements of a Poisson variable within each time period, t (Erickson & Hammond, 1974). Using the calculated values of $E[F_{ijt}]$, a stochastic sample is generated from a Poisson distribution to assign the number of repair part failures for each battalion and the armored cavalry unit during each day. Thus, distribution of repair part failures for each tank unit (battalion or armored cavalry) during the simulation is characterized as a time-stepped nonhomogeneous Poisson process.

All units that are going to be deployed to the Northeast Asia or

Southwest Asia Theaters during the scenario are assumed to begin intensive training from the initiation of hostilities on D-day until 15 days prior to their arrival day in Northeast Asia or Southwest Asia. During this transportation and unloading time of 15 days after departure from the continental U.S. it is assumed that no failures are assessed. Units stationed in Korea simply transition to combat in the Northeast Asia Theater.

Catastrophic destruction of tanks due to combat is also a factor explicitly considered in the model. All destroyed tanks are assumed to be replaced within 24 hours of destruction. The inventory of tanks that are not assigned to Northeast Asia or Southwest Asia are decremented after each catastrophic tank loss, reasoning that every effort will be made to provide committed forces with 100% of their authorized major weapons systems. Improvements in strategic airlift capacity--120 C-17 cargo transports by 2005 (Lund, Berg, & Replogle, 1993, p. 80)--and the purchase of fast roll-on-roll-off cargo ships support that assumption.

2. Intelligent Part Management. As previously noted, following the Persian Gulf War the Total Asset Visibility system was initiated to facilitate world wide visibility of the location, quantity and serviceable status of repair parts. Taking this into consideration, the management of repair parts in this model is performed with complete visibility of repair part inventory status at all levels of stockage down to and including PLL inventories. Repair parts are routed to the downstream inventory location which has the lowest percentage

of authorized fill. This logic is used throughout the supply system, to include selection between routing from the U.S. to the Southwest Asia or Northeast Asia Theaters. Both Southwest Asia and Northeast Asia contingencies are implicitly considered to be of equal priority for repair parts.

Twice each day, at twelve-hour intervals, the percentage fill of every inventory is calculated. Those calculations are used sequentially by the process plan of each part in upstream inventory locations to determine if and where the part is needed downstream. Having determined its next destination, the part process plan requests the appropriate transportation asset for the trip. Repair part inventory status is updated upon the assignment of a part to a new inventory location. Alternative inventory status thresholds for using Air Lines of Communication (ALOC) versus ship transport from the U.S. to the Southwest Asia and Northeast Asia Theaters can be set in the simulation model at the user's discretion.

3. Operational Availability. The status of every tank in every battalion is assessed for supply matériel readiness once every 24 hours. As long as repair parts are available in the battalion PLL when a part is requested, all inoperable tanks in the battalion requiring those parts are repaired and are counted as operationally available. Here it is implicitly assumed that the unit PLL always keeps up with the combat unit and that appropriate maintenance personnel are available to install the required part. No attrition of parts in the theater due to damage, destruction, or loss is considered. It is assumed that

TAV information is available and used with strict discipline in the determination of repair part distribution. This bias is in favor of the supply system, thus somewhat understating the actual requirements for repair parts.

C. Selection of Number of Replications. The scenario being modeled has a given duration and the initial parameters are explicitly set at time zero, leaving only the number of replications to be determined. Choosing the number of replications to execute for each representative repair part is complicated by the fact that over 500 variables representing repair part failures are calculated during each replication. These variables represent the number of failures for tank units in each of five states of nature for each of 150 days[10]. Which variable or variables should be chosen for analysis to determine the number of replications? For this study a confidence interval of 95% was chosen to use in calculating an interval not larger than 15% as large as the mean daily part failures experienced by tank units deployed to the Northeast Asia and Southwest Asia Theaters.

The classic methodology as outlined in Ross (1989, p. 525; 1990, p. 97) for determining when to stop making additional replications was used. The method makes use the equation for determining the 95% confidence interval for a variable, X: $\overline{X} \pm \frac{1.96 \cdot s}{\sqrt{n}}$ where $\overline{X}$ is the sample mean, **n** is the number of replications, **s** is the sample standard deviation and $\mathbf{1.96 = z_{(.025)}}$ for the

[10]The days in which there are no tanks in a particular state do not have statistics calculated or recorded, therefore less than the maximum of 750 variables are calculated during the simulation of the scenario.

standard normal distribution. The number of trial replications is chosen to be greater than 30 to allow use of the standard normal distribution as opposed to the t-distribution for determining a confidence interval. An initial number of 32 trial replications was chosen. Running trial simulations of 32 replications for representative part 100 yielded an average confidence interval over the scenario of ± 13.62% of the mean daily failures for tank units in Northeast Asia and 11.36% of the mean daily failures for tank units in Southwest Asia. As both of these values were less than 15% of the mean, the value of 32 replications was deemed acceptable.

D. Random Number Stream Bias Check. Separate seeds are used to generate individual common random number streams for the stochastic determination of the number of failures within each battalion on each day. Trial simulation runs were made for seven of the representative repair parts using the random numbers generated by the simulation software. The results for the cumulative repair part failures were then compared to the same representative parts but using the antithetic variates of the original random number stream. The cumulative results varied less than 3%. Therefore, any bias inherent in the random number streams appear to be negligible over 32 iterations.

XXI. OBJECTIVE 1: Repair Part Failure Profiles

A. Discussion of Analyses. The simulation results for Objective 1 are presented in two ways. The first method of analysis is to calculate the 95% confidence interval of the expected value of the number of failures generated in the simulation. The second method is to calculate a 95% tolerance interval for the result of one additional simulation iteration. Equations to calculate both a confidence interval and a tolerance interval are presented below (Pritsker, 1986, pp. 38-40):

$$\bar{X} \pm (s)\frac{z_{(1-\alpha/2)}}{\sqrt{n}}$$

Confidence Interval

$$\bar{X} \pm (s)(z_{(1-\delta/2)})\frac{(2n+1)}{(2n)}\sqrt{\frac{n-1}{\chi^2_{\delta\ (\nu=n-1df)}}}$$

Tolerance Interval

where 100(1-α)% = Percent Confidence or Percent Tolerance Interval
For a 95% Confidence or Tolerance Interval, $\alpha = 0.05$

$$\delta = 1 - \sqrt{1-\alpha}$$

n = number of sample values generated by simulations

$\bar{X}$ = sample mean

s = sample standard deviation

$z_{(1-\alpha/2)}$ = value for percentile of standard normal distribution

$\chi^2_{\delta\ (\nu=n-1)}$ = 100δ percentile of the Chi-Squared distribution with ν degrees of freedom.

The widespread use and understanding of confidence intervals motivates the discussion of the analysis using that methodology. However, because wars are generally singular events, as opposed to a repeated activity, and we desire to predict the outcome of a war through the use of a stochastic simulation model, then the argument for the validity of the upper the 95% tolerance limit is the more appropriate procedure. As can be observed in their equations, the confidence interval and tolerance interval calculations are related to the mean and standard deviation of the sample by a constant coefficient when analyzing a given set of data. In this demonstration, given 32 simulation repetitions and a desire for a 95% level of confidence, the confidence interval around the sample mean is calculated to be **± 0.3465*s**, where ***s*** is the standard deviation of the sample. Using the same sample data, the 95% tolerance interval around the sample mean for predicting the result of one additional simulation repetition is calculated to be **± 3.016*s**. Therefore, the prediction interval around the sample mean is **(3.016/0.3465) = 8.7046** times larger than the range of the confidence interval calculation using the same simulation data. If the analysis of the simulation results performed using confidence interval calculations give cause for concern, the prediction interval calculation can only be more alarming.

B. Confidence Interval. Objective 1 in the modeling methodology demonstration is to determine stochastic estimates of the daily quantity of failures for the family of 100 representative repair parts of the Abrams tank. These failures are generated under the assumption that each tank battalion in

Southwest Asia and Northeast Asia has its full complement of 70 tanks and the armored cavalry unit in Northeast Asia has 148 tanks, each in an operationally available state at the start of each day. Tanks damaged beyond repair at the unit level are recovered and replacements provided within 24 hours. Replacement tanks for those damaged beyond repair are removed from the quantity of those tanks in the fleet that are not assigned to combat units scheduled to go to Northeast Asia and Southwest Asia.

The combat scenario is simulated for 32 iterations for each of the 100 representative repair parts. The upper and lower 95% confidence limits around the mean daily quantity of failures are calculated. These daily failures are summed to create a cumulative failure profile for each representative repair part.

The range of cumulative repair parts required by the fleet of 7,778 Abrams tanks for the 100 representative repair parts during the 150-day duration of the scenario is shown in Figure 15. Each line plotted on the chart represents the cumulative upper 95% confidence limit above the mean number of failures for an individual representative repair part. There are four distinct groupings or envelopes that appear to grow from near the origin of the graph. These groupings are the result of the spread of the failure factor mesh, and in particular the impact of FFII. The impact of FFII is heavily influential over the total number of repair part failures during the early days of the scenario. During the first 33 days only 280 tanks (of a total of 3088 that will eventually be deployed to the Southwest Asia or Northeast Asia Theaters) are deployed (see Figure 12).

During this time there are 4,690 tanks that are experiencing part failures at FFI, 2,808 tanks experiencing failures at FFII and 280 tanks experiencing combat related failures. The effects of differing combat failure factors, FFIV, become increasingly prominent and visible on the chart as the percentage of tanks deployed to Southwest Asia and Northeast Asia increases. At all times the balance of the fleet, 4,690 tanks at the start of the scenario, provides a steady part consumption due to FFI. The gap between the lower three envelopes and the upper envelope of failures is intentional. The concentration of actual failure

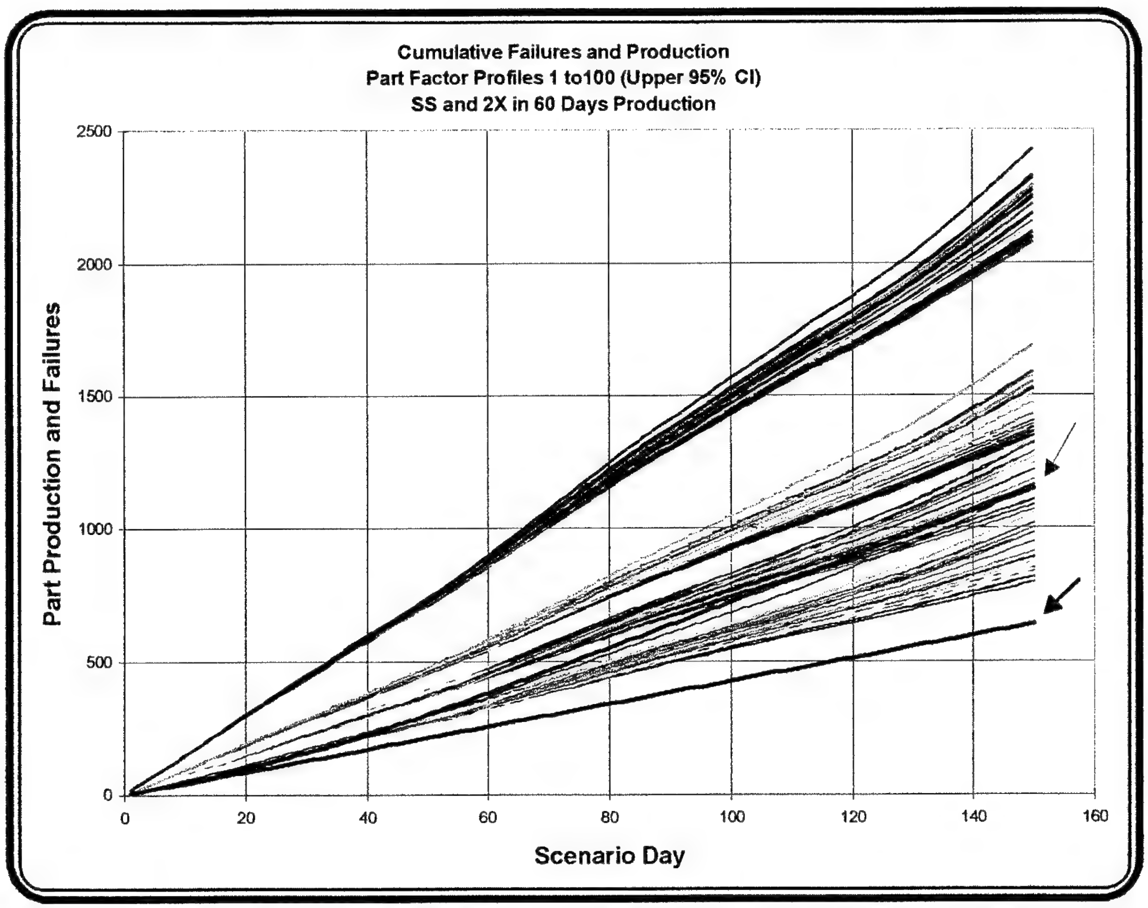


Figure 15: Cumulative Daily Failures of Parts for Abrams Fleet in Scenario

factors tends to be in the area covered by the lower three envelopes, and the upper envelope covers the repair parts that have relatively high failure factor profiles. The gap is simply a reflection of the failure factor profiles developed from the actual data. If the data generated in this manner are too sparse, the mesh (Table 7) is too large and must be selected with greater care. Additional simulation data may be generated to fill any areas of interest that are not sufficiently covered as a result of the chosen initial mesh.

To assist in evaluating the relative importance of the failure profiles in Figure 15, a cumulative steady state (peacetime demand rate) production curve and a cumulative production curve representing an increase to twice-steady-state-production-after-60-days-from-the-start-of-the-scenario curve (2X in 60 Days) are also plotted as bolder lines. These production curves are based on pre-D-day demand histories, FFI. Arrows point to the two curves for quick identification relative to the representative repair part failure curves. The steady state curve, identified by the lower arrow, is purple. The 2X in 60 Days curve, identified by the upper arrow, is red. The steady state production curve is plotted because it is the production rate that will be economically viable during the next decade as the Army sustains the fleet of Abrams tanks. A recurring requirement for repair part production is assumed. In keeping with the desire to control bias in the favor of the supply system, the 2X in 60 Days cumulative production curve is generated under the assumption that production increases immediately by increments of 1/60 of the peacetime or pre-D-day production rate

until a rate twice (2X) the rate on D-day is achieved.

The 2X in 60 days production curve has historical roots. During the Cold War, contractors were often contractually required to maintain the capacity to ramp up to twice their normal peacetime production within 60 days. Some of the repair part manufacturers that continue to supply repair parts to the Abrams tank over the next decade may currently have that production capacity already inherent in their manufacturing facilities. However, alternative uses for this capacity will certainly be found over the next 15 years unless an economic incentive is provided to maintain that idle capacity.

The cumulative requirement for repair parts as represented by failures during the scenario range from a low of 795 failures for representative part AG1 to a high of 2,432 for part AG100. Representative repair parts are labeled AG1, AG2, . . . through AG100 for identification as indicated in Appendix F. It is readily apparent that the demands for repair parts at the 95% confidence limit will exceed the steady state peacetime production quantity at all times. The cumulative steady state production during the 150-day scenario is 639 repair parts. The cumulative ramped up 2X in 60 days production yields 1,148 repair parts over the same 150-day period.

For clarity, the data represented in Figure 15 are presented in four charts containing 25 representative parts each in Figures 16 through 19. Each of the 100 representative repair parts are identified in the legends. The steady state and 2X in 60 Days cumulative production curves are also plotted for reference.

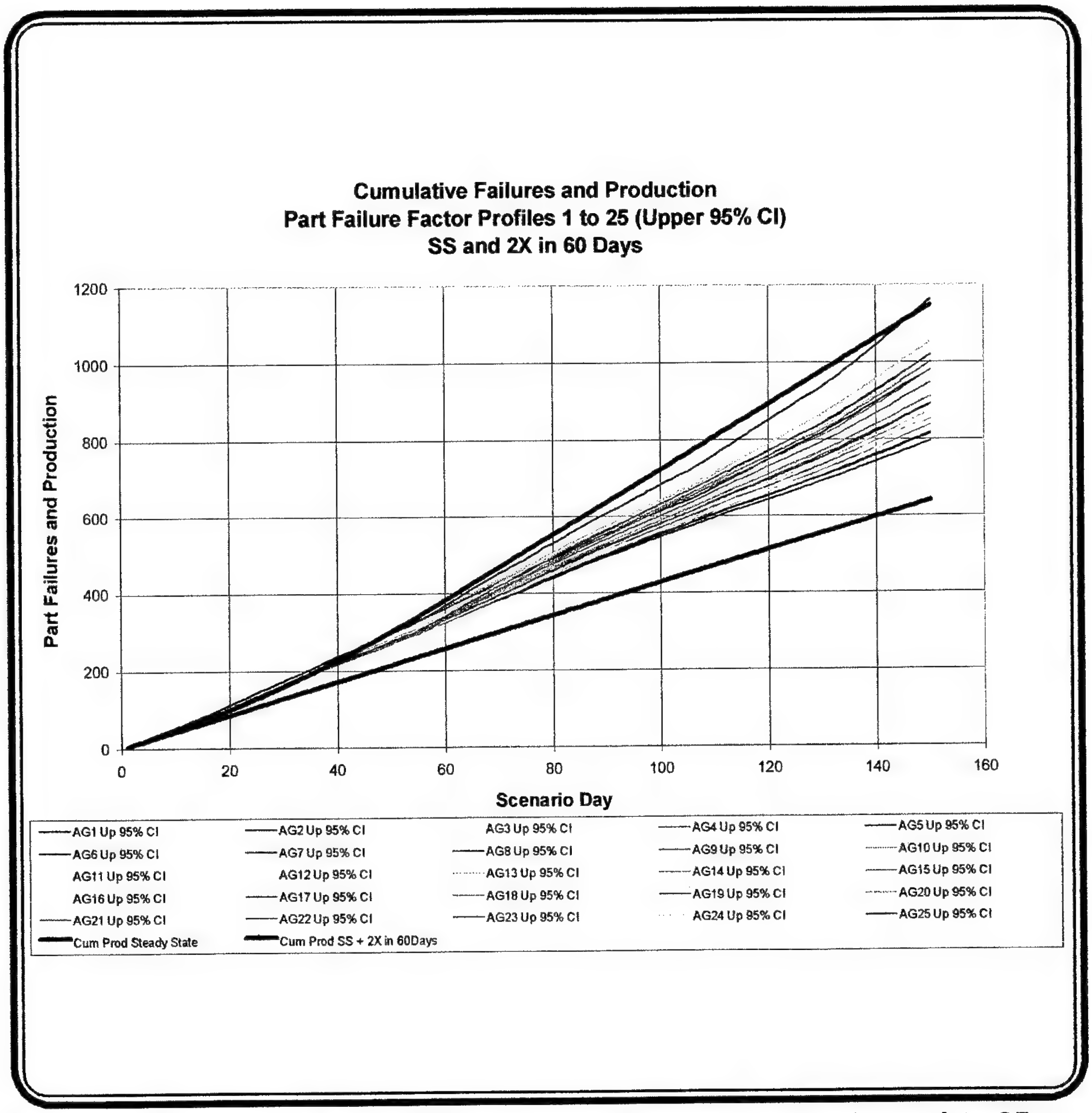


Figure 16: Cumulative 95% CL Failures for Representative Parts 1 to 25

The chart in Figure 16 represents the upper 95% confidence limit spectrum of cumulative repair part failures that would be expected given repair parts with the failure factors of representative repair parts AG1 through AG25. Production at the 2X in 60 days rate nearly equals or exceeds demands for repair parts with these failure factor profiles.

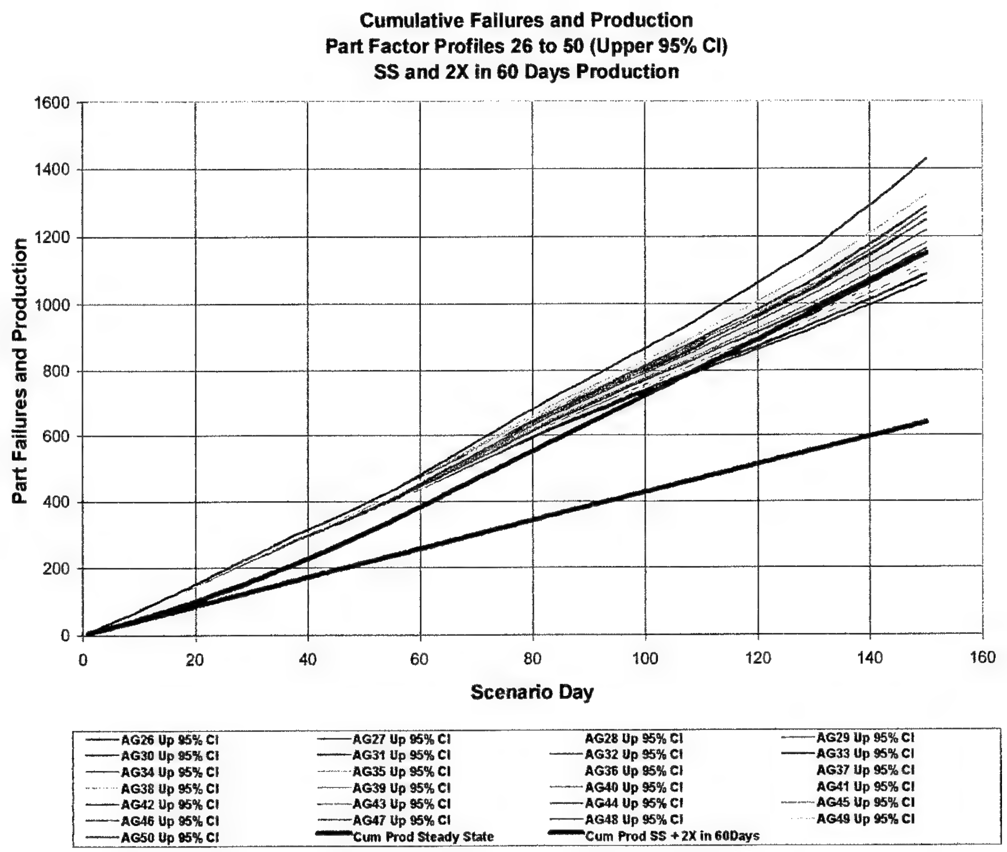


Figure 17: Cumulative 95% CL Failures for Representative Parts 26 to 50

The chart in Figure 17 represents the upper 95% confidence limit spectrum of cumulative repair part failures that would be expected given repair parts with the failure factors of representative repair parts AG26 through AG50. Production at the 2X in 60 days rate is not adequate to replace the quantity of demands of any of these representative parts until after day 100 of the scenario.

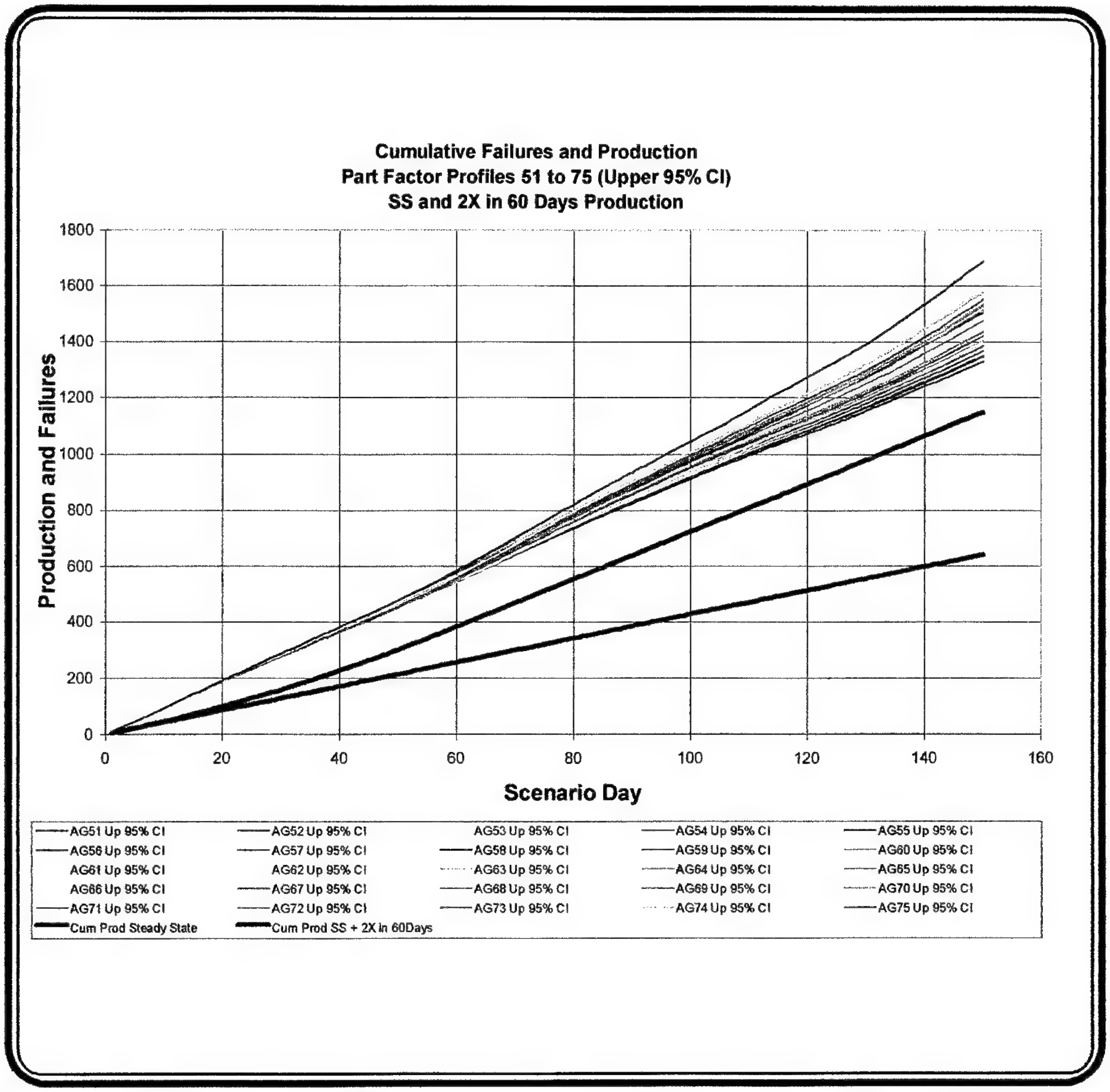


Figure 18: Cumulative 95% CL Failures for Representative Parts 51 to 75

The chart in Figure 18 represents the upper 95% confidence limit spectrum of cumulative repair part failures that would be expected given repair parts with the failure factors of representative repair parts AG51 through AG75. For the first time, the 2X in 60 days cumulative production is not greater than the anticipated demand for any of the representative repair parts.

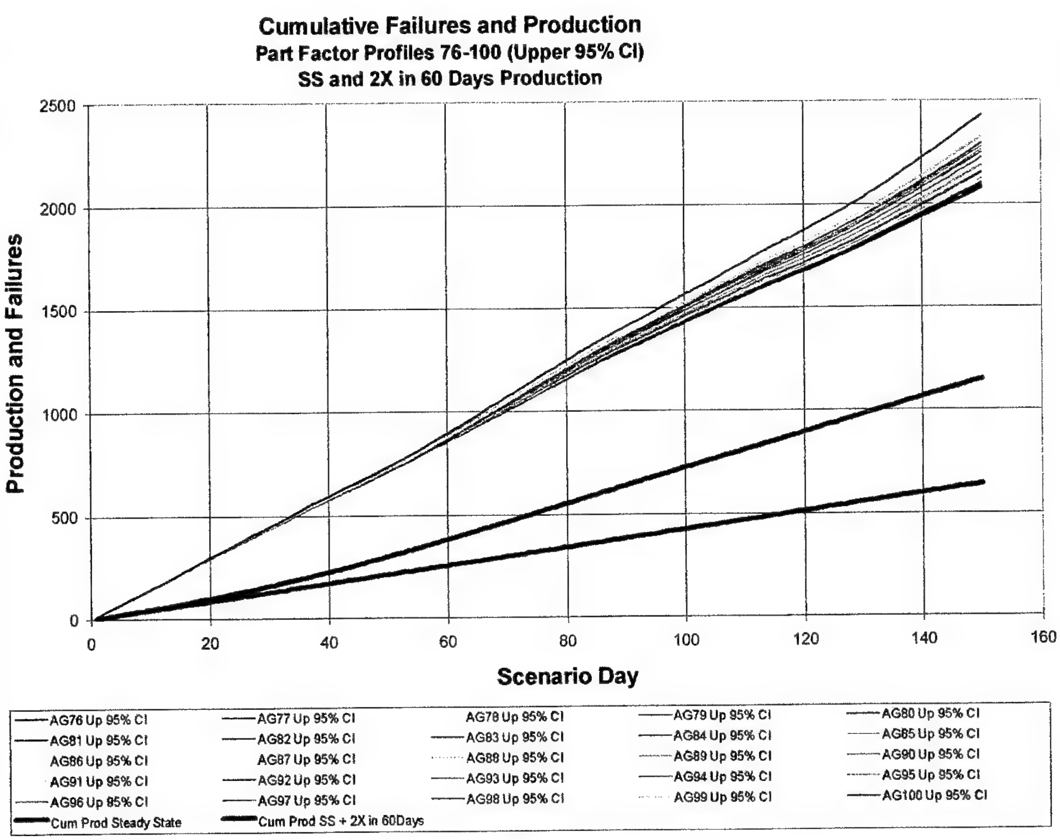


Figure 19: Cumulative 95% CL Failures for Representative Parts 76 to 100

The chart in Figure 19 represents the upper 95% confidence limit spectrum of cumulative repair part failures that would be expected given repair parts with the failure factors of representative repair parts AG76 through AG100. These are the highest failure factor profiles in the mesh. Although the number of critical repair parts that have failure factors in this range is a small proportion of all critical repair parts, the impact of their failure results in a nonoperationally

available tank and negatively impacts combat power available to the battalion suffering the loss. The failure of one critical item effectively takes the entire weapons system out of combat.

These cumulative repair part failure curves represent the minimum required quantity of repair parts to sustain the fleet of Abrams tanks in the two major regional conflicts scenarios given. Because the data are captured separately in the simulation based on the five states of nature that tanks experience in the model, additional constructions of the scenario may be developed. As previously indicated, these states of nature are:

(1) Scheduled for deployment to NEA (but not yet there)

(2) Deployed in NEA

(3) Scheduled for deployment to SWA

(4) Deployed in SWA

(5) Not Scheduled for deployment to NEA or SWA.

The failure curves for the tanks in and scheduled to go to the NEA Theater and the SWA Theater may be aggregated over any time horizon to generate failure curves as desired. The relationship provided in the scenario as demonstrated here is among the most stressing from the Bottom Up Review as interpreted in TAA 2001.

These data may also be scaled based on any posed quantity of tanks authorized in a tank battalion and the armored cavalry unit because the mean number of failures during each day is the product of the number of tanks in a unit

and the calculated number of failures per tank per day for the combat environment of the tank battalion on that day. Therefore, for example, if the actual number of tanks in a battalion were proposed to be 62 instead of 70 (and the armored cavalry unit reduced proportionately) then the mean failure curves for each part could be scaled by a factor of $\frac{62}{70}$.

Again, the base failure factor assumed in generating these failures assumed a failure rate of FFI = 20 failures per 100 tanks per year. Parts with other failure factors may scale these results proportionally by multiplying them by a factor of $\frac{FFI_{actual}}{20}$.

C. Tolerance Interval. A graph of the cumulative upper 95% tolerance limits using the simulation data for representative parts AG1, AG50 and AG100 is shown in Figure 20. Here the upper and lower tolerance limits around the sample mean are ± 8.7 times larger than the upper and lower confidence limits. In the most extreme case, a repair part with the failure factor profile of representative part AG100 would require a cumulative inventory and production capacity to provide the demand for repair parts at the 95% tolerance interval is 5,384 parts, or 2.21 times larger than the cumulative upper 95% confidence limit. This represents a potential demand that is over 8.4 times the cumulative steady state peacetime production of 639 parts or over 4.6 times the cumulative 2X in 60 days production during the scenario.

To have 95% confidence that the quantity of repair parts with a failure factor profile of representative part AG100 in the given scenario will meet the

potential demand, an inventory equal to 3.05 years of peacetime demand if production remains at peacetime levels during the war or 1.36 years of peacetime demand if production is able to ramp up to 2X in 60 Days.

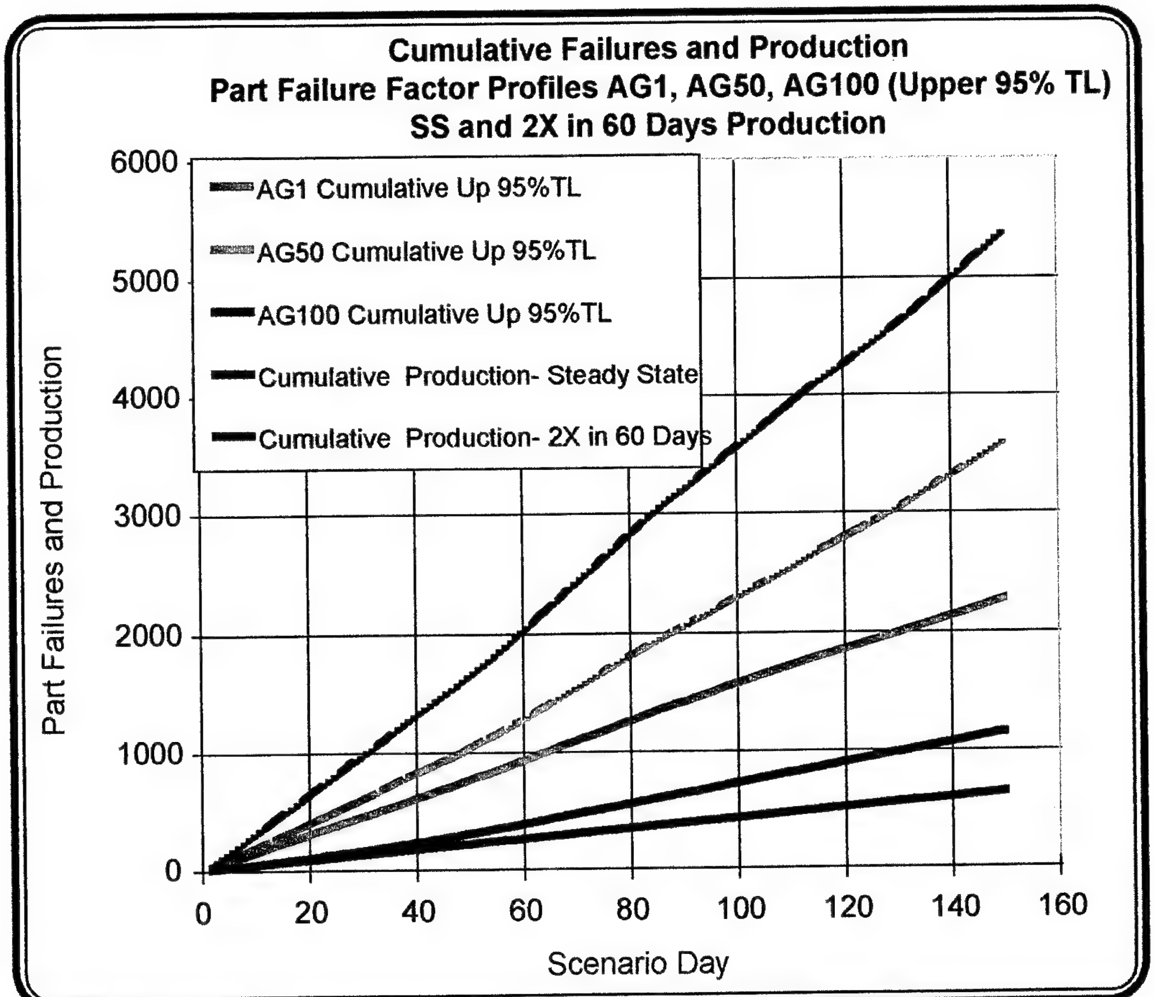


Figure 20: Cumulative Upper 95% Tolerance Limit for Representative Parts 1, 50, 100

XXII. OBJECTIVE 2: Comparison of Alternative Policies.

The identical failure curves just discussed will be experienced by any tank unit that maintains all of its tanks in operational availability status during the simulation. To aid in comparison of alternative supply and inventory policies, the simulation is constructed to use a separate random number stream for each stochastic failure process in the battalions as well as any production function supplied for consideration. In this manner, alternative solutions proposed can be directly compared taking advantage of the fact that alternatives are calculated using common random numbers to reduce the variance of the difference between alternative policy sample mean results (Pritsker, 1986, p. 745). Using the model to compare alternative inventory and production capacity policies is further described in Appendix G.

This type of simulation would be used in the cases where there was a question concerning the actual capability of a policy to support the weapons system. Statistics may be gathered at any stage of the repair part movement and restrictions concerning transportation may be added. The results of the simulations generate a lower bound on the minimum repair part requirements.

As a demonstration of Objective 2 analysis, the simulation was executed under these conditions:

(1) Conflict first started in NEA

(2) Conflict in SWA lags NEA by 45 days

(3) Unit PLLs filled to a 15-day supply based on FFI

(4) Additional 30-day supply in ASLs and Depot.

(5) Part Failure Factors: FFI = 390

FFII = 648

FFIV SWA = 43

FFIV NEA = 132

Two cases were executed. In the first case no additional production was allowed, so the war was totally "come as you are." The resulting operational availability of the tanks assigned to each theater is charted in Figure 21. In the

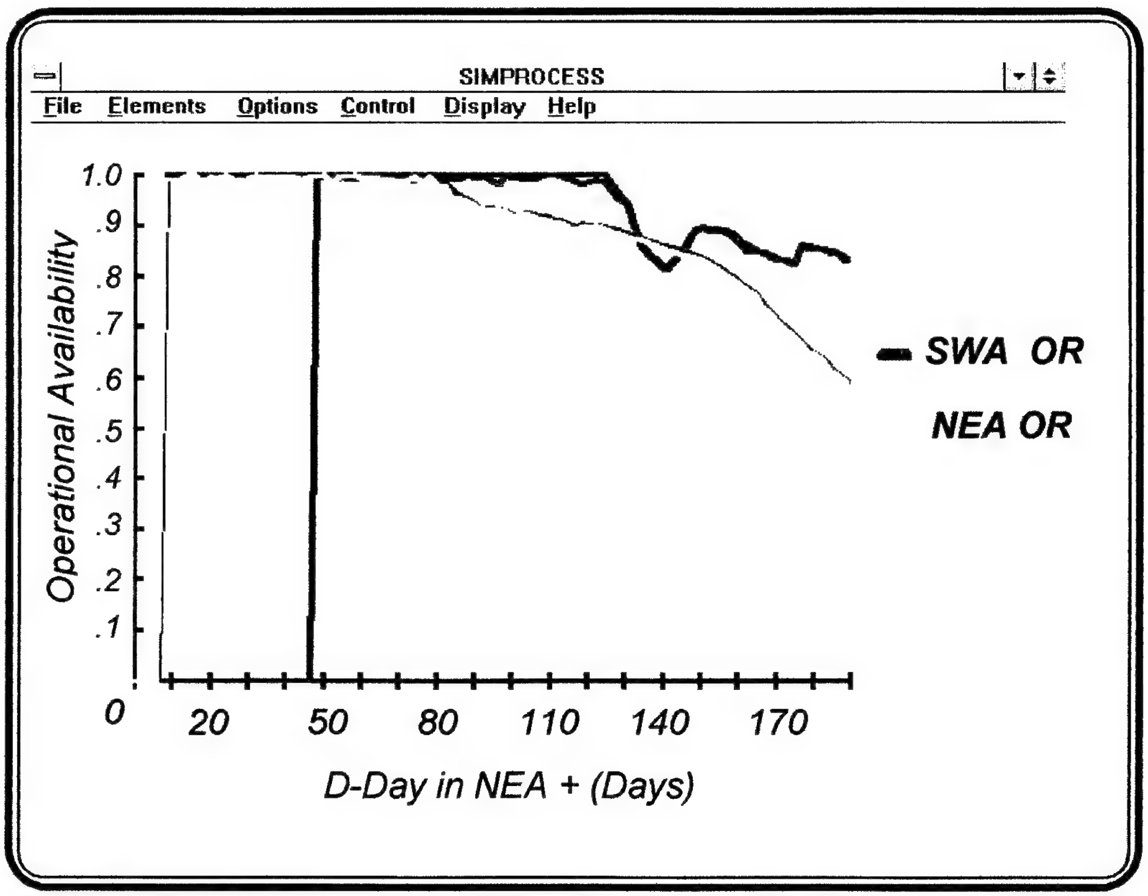


Figure 21: Case 1 "Come as you are"

second case, production at the 2X in 60 Days rate was allowed in addition to the previously listed initial inventory. The resulting operational availability statistics are plotted in Figure 22.

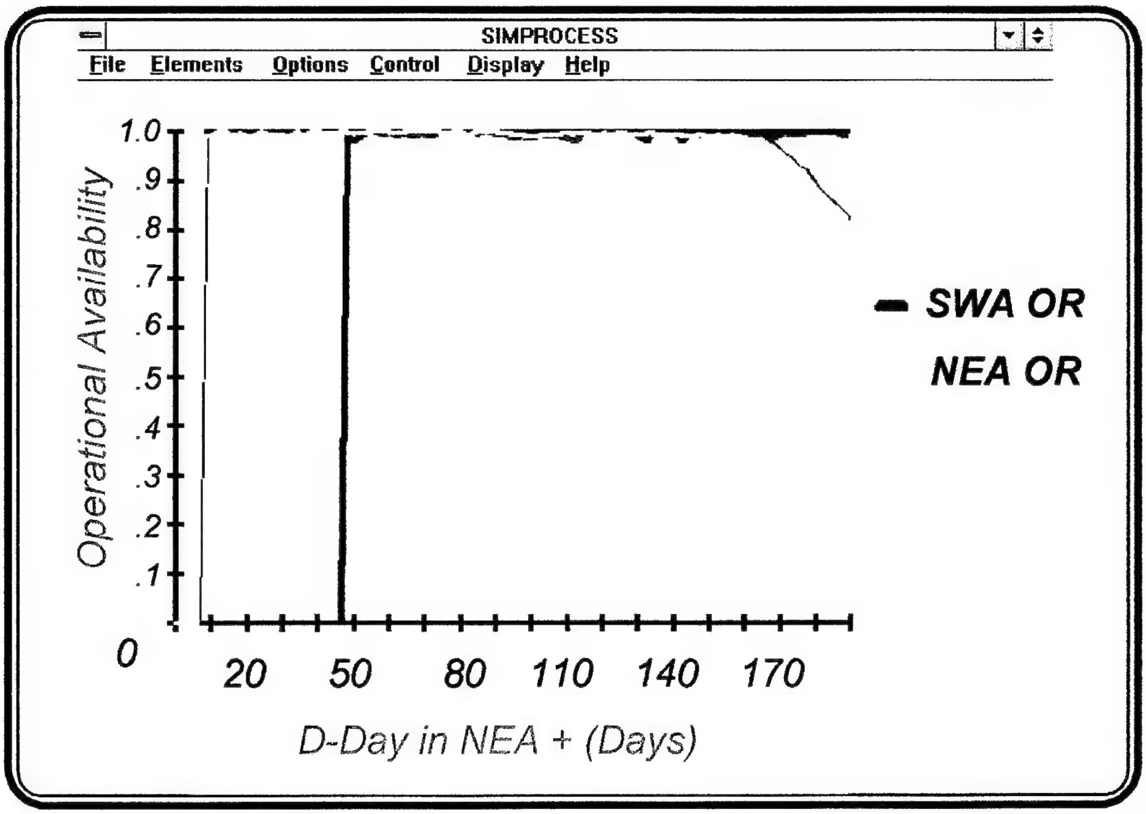


Figure 22: Case 2 "2X in 60 Days Production"

The operational readiness rates improve during the course of the scenario even though there is no new production because the second wave of incoming units arrive with their full complement of PLL parts. However, the resulting operational availability statistics of less than 82% for tank units in Northeast Asia by the end of the war due to a shortage of one repair part would be totally unacceptable.

XXIII. Analysis.

A. Production and Demand Comparisons. Subtracting the failure profiles from the 2X in 60 days production profile in Figures 16 through 19 yields production shortfalls as negative numbers. These results are shown in Figures 23 to 26. No plots for the steady state production are made because the quantity of repair part failures at the 95% upper confidence limit is always greater than production at steady state.

The chart in Figure 23 shows that the 2X in 60 day production rate is adequate in the long run, but requires the use of inventory until as late as day 48 of the scenario. Cumulative demand is greater than cumulative production

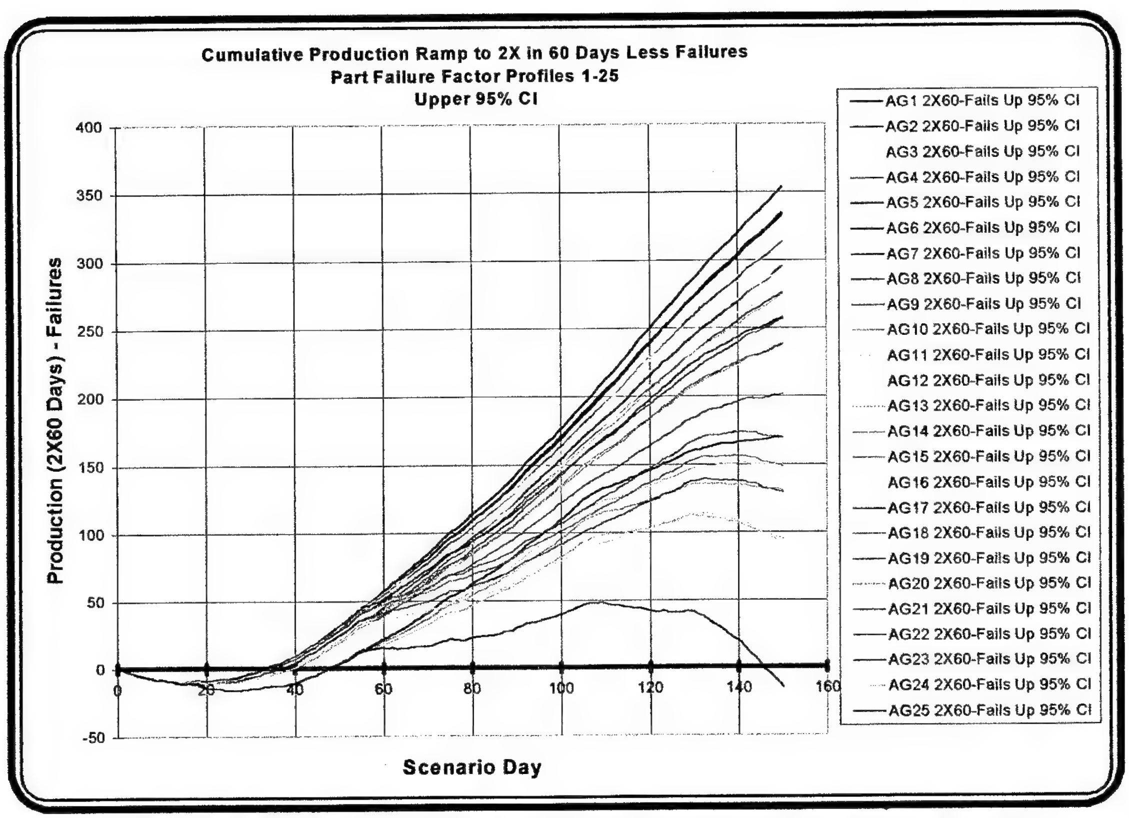


Figure 23: 2X in 60 Days Production Less Demands for Parts 1 to 25

for representative part AG25 in the final 3 days of the scenario. The charts in Figures 24 through 26 show the progressively larger difference between cumulative 2X in 60 days production and the cumulative expected failures at the upper 95% confidence limit.

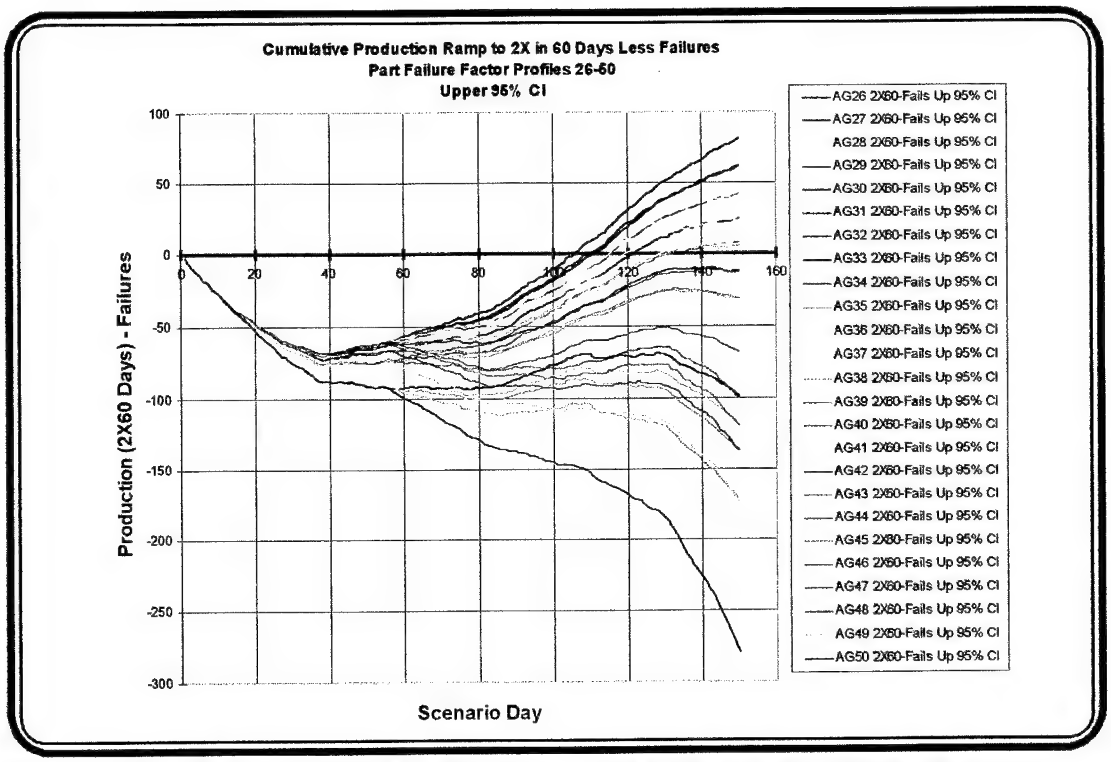


Figure 24: 2X Production in 60 Days Less Failures for Parts 26 to 50

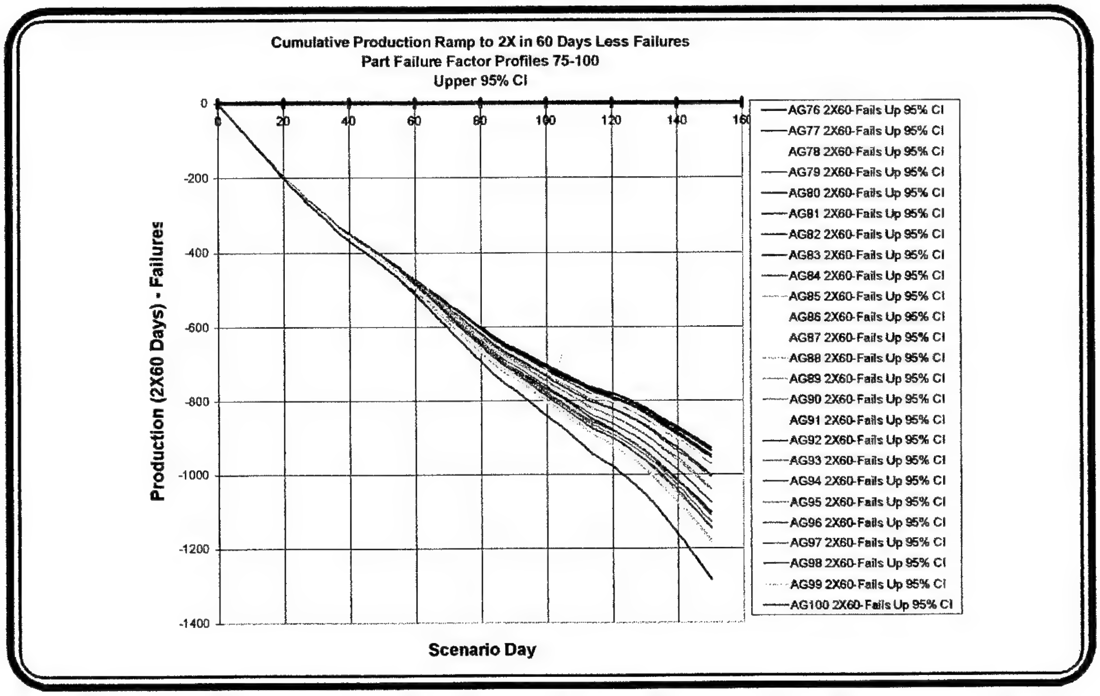


Figure 26: 2X Production in 60 Days Less Failures for Parts 76 to 100

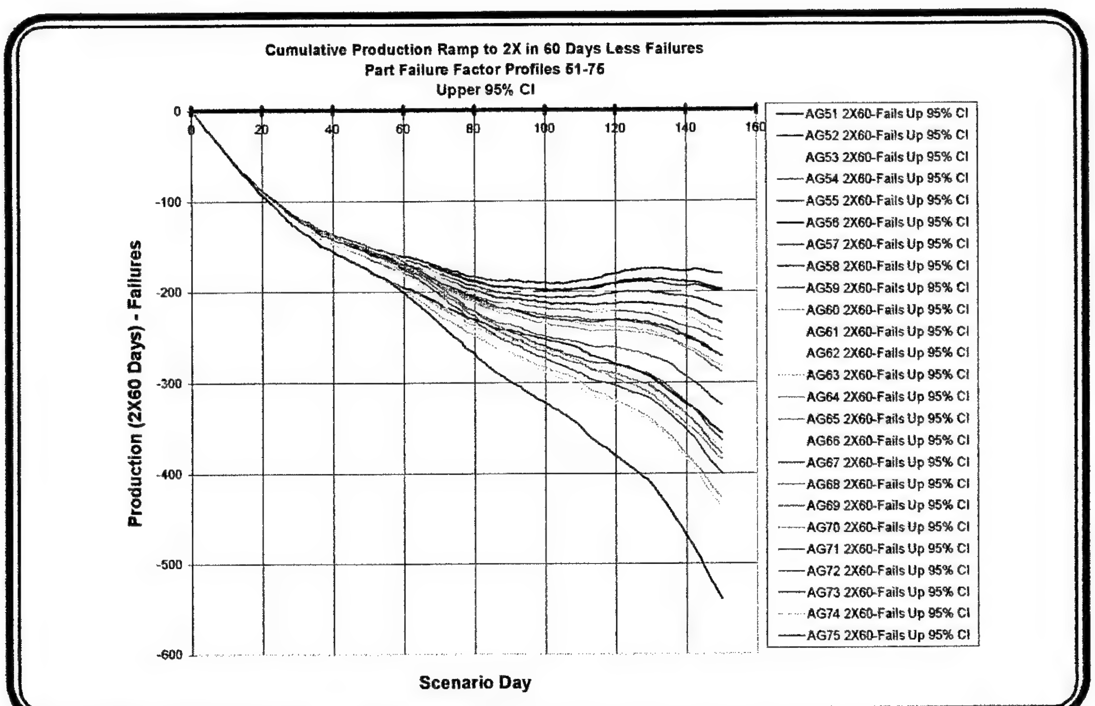


Figure 25: 2X Production in 60 Days Less Failures for Parts 51 to 75

Another revealing way to observe the data is presented in Figure 27. Here the mean and upper 95% confidence limit of cumulative repair part demands for each representative part are sorted from least to greatest demand quantity. The cumulative production quantity from a steady state production (639 parts) and the 2X in 60 days total production quantity (1,148 parts) during the scenario are also plotted as a reference. A total of 35% of the representative repair parts experience cumulative failure quantities greater than the 2X production quantity. This jumps to a level of 65% of the representative repair part population if the upper 95% confidence limit is chosen for comparison.

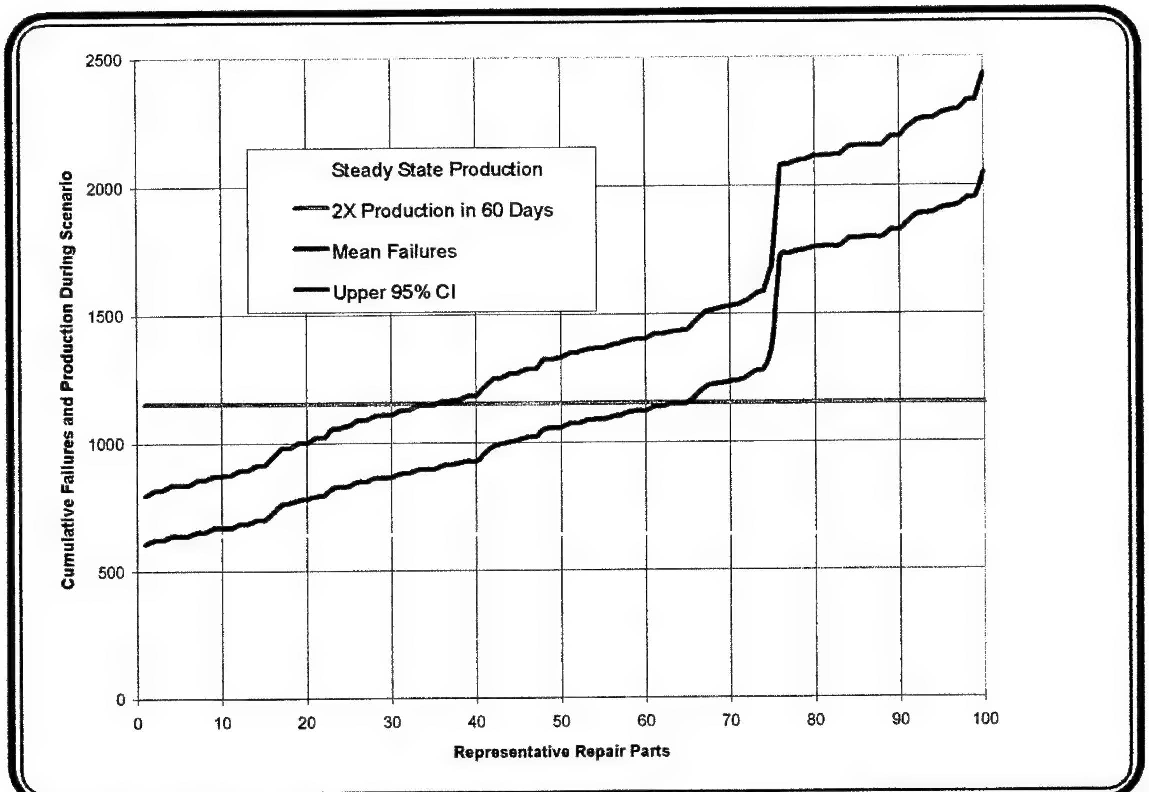


Figure 27: Cumulative Demands and Production Profiles

total expected demand of 192 parts. Adding these parts to the production curves still results in 50% of the representative parts having an upper 95% confidence limit demand greater than the sum of production plus a 45 day inventory. The representative repair parts AG76 through AG100 have expected failures greater than the sum of 2X in 60 days production and a 45 day supply of inventory.

These differences between daily total stock status and repair part demand as measured by the daily failures represents the "D-day to P-day" analyses previously mentioned. In the instances where the cumulative daily demand is greater than the cumulative available supply of the repair part, the difference represents the minimum number of Abrams tanks that would be non-operationally available due to lack of repair parts. Unequal demands for repair parts in the combat units over the duration of the simulation would likely result in local battalion shortages of repair parts that would cause a larger number of Abrams to be NMCS because some parts were being held in PLL or ASL in other locations that are not immediately available.

B. Daily Production Multiples. Normalizing the daily upper 95% confidence limit of repair part failures against expected daily peacetime failures reveals the required production capacity on a daily basis as a multiple of the steady state peacetime rate. This multiplier indicates the daily multiple of normal

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[11]The commander of allied forces in the Persian Gulf War required a 45 day supply of ammunition and supply matériel to be located in theater prior to any ground attack against the Iraqi army.

steady state peacetime rate. This multiplier indicates the daily multiple of normal peacetime capacity that an agile manufacturer would experience given a repair part with these failure factor profiles. In Figure 28 six of the parts from the representative mesh (AG1, AG10, AG35, AG50, AG75, and AG100) are plotted. The daily production demand ranges from a multiple of 1 (meaning no impact) to a high of 4.4 times daily expected peacetime demand. The ratio of peacetime expected demand to the upper 95% tolerance interval would be much larger.

From this chart one may observe that a production rate of slightly over two times the expected peacetime part failures would provide the required production for 75% of the parts in the representative failure factor mesh.

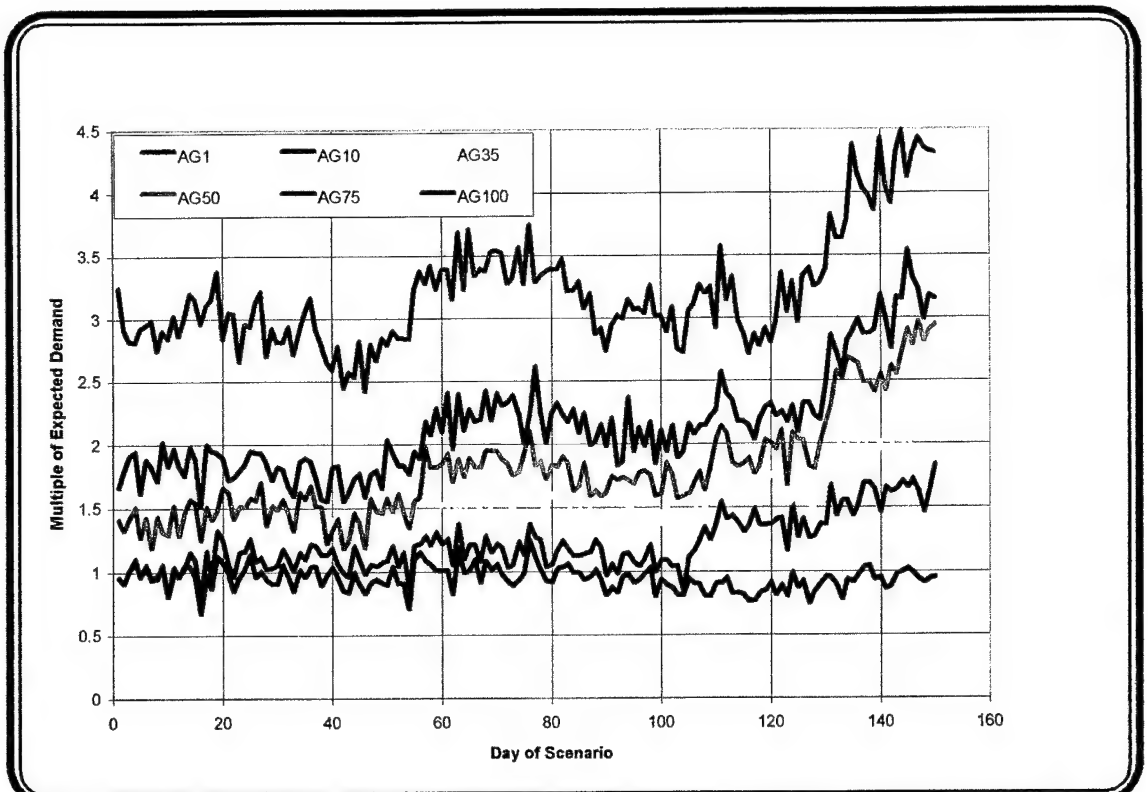


Figure 28: Selected Daily Ratios of Combat versus Peacetime Demands

the Abrams tank contains 595 critical repair parts. These parts range from critical seals and washers costing less than a dollar each to the entire engine costing $487,252. All of these critical component parts must function for the tank to be operationally ready. The daily probability of a tank being in a state of operational availability can be written as:

$$P(OA) = \prod_{i=1}^{595} [1 - P(\mathit{Unavailable\ Part}_i | \mathit{Part}_i\ \mathit{Fails})(P(\mathit{Part}_i\ \mathit{Fails}))]$$

Using this equation, if all parts were considered to have identical failure rates, and part availability rates and the desired P(OA) is 0.90, then the average probability of the part being in a working state must be 0.999823. If a single part among the 595 had a probability of 0.90 of being in a working state, then all others would have to maintain a 100% probability of being in a working state to maintain the P(OA) of 0.90. This serves to highlight the fact that the failure rates of parts have an impact on the operational availability of weapons systems only in those situations where the supply system is inadequate. For example, if a part has a daily probability of 20/36,500 of failure, then the P(Part Available|Part Fails) must be ≥ 67.7%. The required probability of part availability that will maintain a P(OA) ≥ 0.90 escalates toward unity for all other parts as any of the 595 parts experience a probability of availability that approaches 0.90.

D. NEA and SWA Demands Alone. The upper 95% confidence limit of repair part failure profiles generated by the tank battalions and armored cavalry unit in the theater are shown in Figure 29. The expected failures of repair parts with failure factor profiles higher than representative repair part AG75 alone are

with failure factor profiles higher than representative repair part AG75 alone are greater than the expected cumulative 2X production in 60 days. This means that if production were totally dedicated to units in Northeast Asia and Southwest Asia and no other locations, production would not equal demand for actual repair parts with failure factor profiles higher than representative repair part AG75.

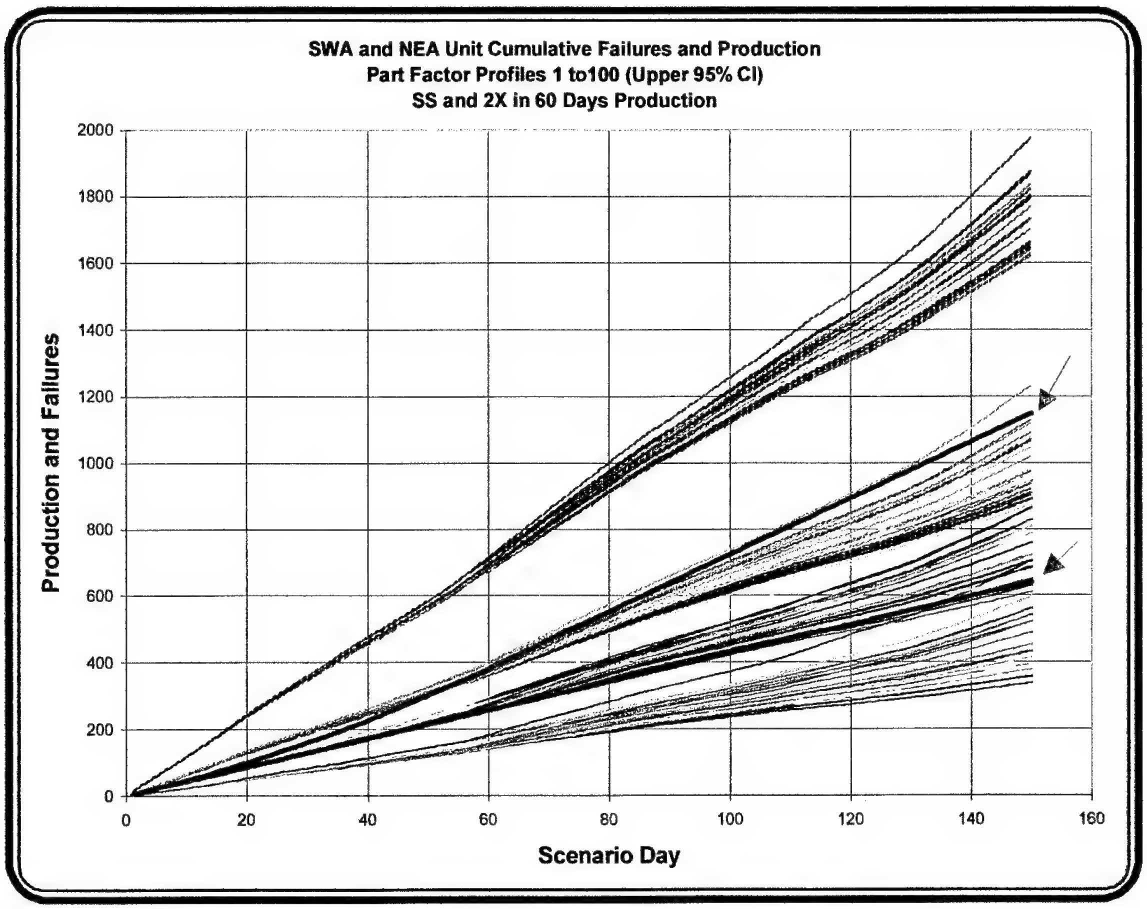


Figure 29: Total Cumulative Failures in NEA and SWA Alone

E. Policy Choices. The manufacturing facilities of repair part suppliers for existing major weapons systems such as the Abrams tank were designed and constructed in the late 1970s and early 1980s. The concept of agile manufacturing was not known, and the enabling technologies were in relative

processing unit was not invented until the early 1980s, years after the first Abrams tanks were in production. It is reasonable to assume that the manufacturing methods and practices developed at that time were not optimized for agile manufacturing. These manufacturers have the capability to manufacture the parts as long as they are adequately economically rewarded in that endeavor. The production rate limitations of existing manufacturers imply the necessity to stock inventory. As has been demonstrated, this inventory quantity is significant for some repair parts and is greater than that provided for in present policy (if it were funded). The significant alternative to purchasing and supporting the storage of that inventory is represented in agile manufacturing. The alternatives represent an economic choice among competing alternatives.

Conventional D-day to P-day analysis would result in a requirement for War Reserve inventory of a minimum number of repair parts that would balance the shortages over production (assuming that the manufacturer was paid to maintain the ability to ramp up production to 2X in 60 days) as shown in Figures 23 through 26. If the manufacturer were to maintain a lesser capacity due to the economic incentives of peacetime demands only, the inventory requirement would be greater. The cost of maintaining the inventory of a repair part over the next 15 years equates to what the U.S. Army would be willing to invest in the development of an agile manufacturing supply source for an individual repair part. The inventory investment cost can be significant when one considers that

the 595 critical repair parts listed on the M1A2 Candidate Item File includes 225 parts which cost over $100, among those are 51 which cost over $1,000, and of those 5 cost over $50,000 each.

The agilization of the military repair part industrial base will not occur without economic incentives and changes in federal acquisition regulations and policies. A basic premise of agile manufacturing is cooperation between user and supplier. "Lowest bidder" repair part acquisition contracting schemes will not support an agile manufacturing supply system. A new contracting system capable of capitalizing on emerging manufacturing technologies must be developed.

XXIV. Conclusions.

The supply of critical repair parts will be crucial to the operational readiness of major weapons systems as the U.S. Army passes through the "procurement holiday" period of the next decade. Former third- and fourth- or lower-tier providers of repair parts are steadily being elevated to first tier suppliers as production of the major weapons systems end. These are the manufacturers that have formerly been implicitly assumed to be able to provide adequate supplies of repair parts during the time of production of the major weapons system. Diligent, part-by-part assessments of inventory and production capacity policy must be accomplished to insure that adequate supplies of repair parts will be available during two nearly simultaneous major regional conflicts.

One must remember that the results presented in this demonstration of the Southwest Asia and Northeast Asia scenarios is biased. The bias has been consistently in favor of the military supply system. At no time in the simulation are repair parts subject to attrition from damage, enemy actions, loss or environment. Transportation is always available to transport parts as required. Maintenance personnel are always available to replace the damaged repair part when the part is available. No secondary effects of weapon damage is considered in the SPARC methodology that is used in the calculations of Failure Factor IV. Given this bias, the required number of repair parts may be considered to be a lower bound on the actual number of repair parts that would be required in the Southwest Asia and Northeast Asia scenarios demonstrated.

The fact that confidence limits--as opposed to tolerance limits--were used underscores that position.

It has been demonstrated that a number of critical repair parts for the Abrams tank have failure factor profiles which require more parts than can be produced by increasing the production rate to twice the mean peacetime production rate over a 60 day period. Each demand for these parts which cannot be satisfied by inventory available at the start of the contingency translates into a nonoperationally ready tank in the fleet. A combination of repair part shortages would result in a significant loss of combat power due to nonoperational weapons systems awaiting repair parts.

The gravity of the potential shortfall can be readily observed in Figure 30. Here the cumulative **lower** 95% and upper 95% confidence limits for representative repair parts AG76 to AG100 are plotted. The repair part requirements over production are readily apparent. In all cases even the <u>lower 95%</u> confidence limit (with the 2X in 60 Days production rate) is insufficient. A diligent part-by-part analysis of the critical repair parts for all major weapons systems must be continuously undertaken to assess the required balance of inventory and production capacity required to achieve an acceptable level of confidence that adequate quantities of repair parts will be available at the start of a major regional contingency. Waiting until the start of a major regional conflict will be too late for those parts where inadequacies in the combined available quantity in inventory and production exist.

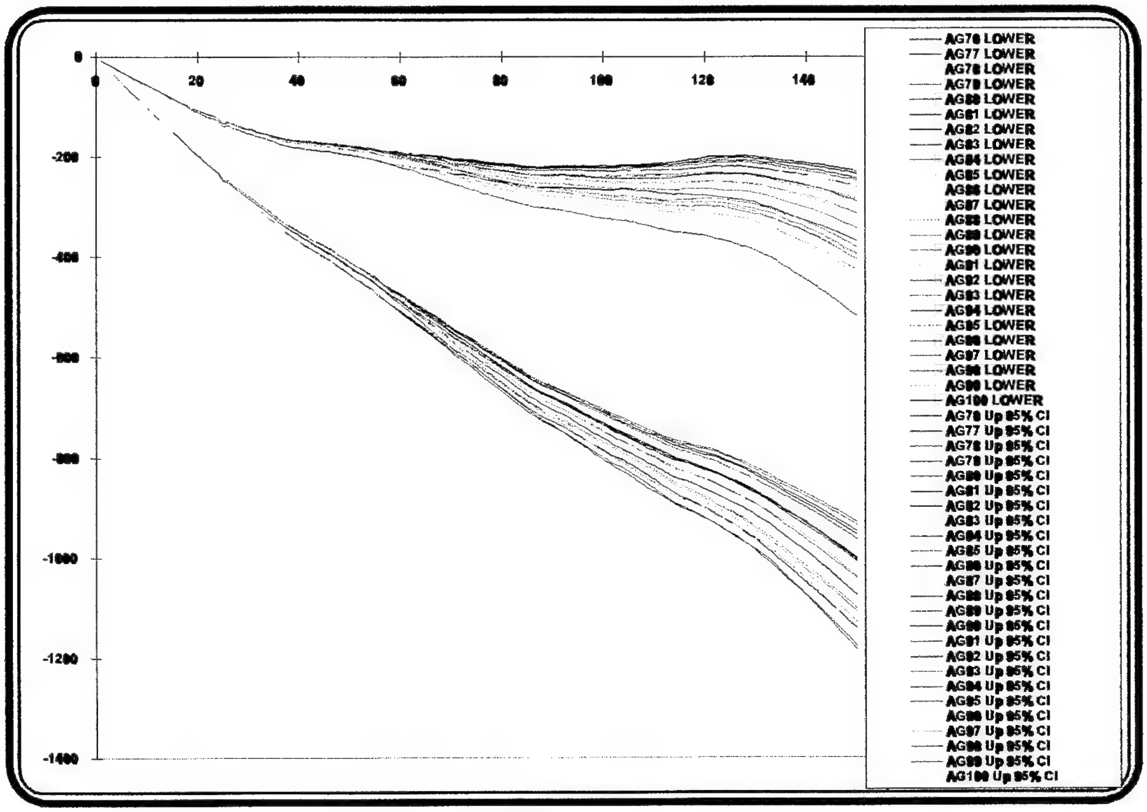


Figure 30: Difference Between 2X Production in 60 Days and the Lower and Upper 95% CL for Representative Repair Parts AG76 to AG100

Given the "Assault on Inventories" and the dismemberment of the Abrams production industrial base, the message is clear. Inventory and supply policy for critical repair parts must be as intensively managed at the individual repair part level as was previously done for the end items and their major components. The risk that must be avoided is the assumption that agile manufacturing practices spread to the military repair part industrial base in similar fashion as one may observe in the commercial industrial base. Producers of repair parts for newly developed weapons systems will have the advantage of using agility. Established repair parts manufacturers supporting a fleet of older weapons

systems may not.

Logisticians responsible for repair part policy must now continually appraise the production capacity of the industrial base to produce individual repair parts. Capacity will continue to exist only so long as there is an economic incentive to maintain it. As the Army uses its budget for repair parts, the industrial base will respond. Pressures, both fiscal and political, to move toward lower inventories or agile manufacturing practices must be individually analyzed. There is no "one size fits all" in this changing industrial environment. The quantity of work for the logistician increases as each major weapons system transitions from production to fleet sustainment and the repair part suppliers remain. Failure to individually measure the industrial base for each individual critical repair part, and continually evaluate and revise production and inventory policy accordingly, risks unintentional degradation of the operational availability of a fleet of major weapons systems in a future major regional conflict.

Analyses of the costs of supporting the development of agile manufacturing capacity in the industrial base versus current practices are warranted. The impact of expanding agile manufacturing in the industrial base while obtaining increased production capacity for a major regional contingency at some indefinite time in the future makes sense. Expenditure of resources on inventory that may never be used versus expending resources on the industrial base that can be used continuously for commercial purposes while being available for wartime production requires serious consideration.

The methodology developed in this research can be used to identify those critical repair parts that merit special attention based on their failure factor profile. Alternative inventory and production capacities may be proposed and modeled to determine their relative performance in providing adequate repair part availability during a contingency as measured by the impact on the operational availability due to supply of a weapons system in a given major regional contingency.

The Army and the nation owes its soldiers the effort to investigate and mitigate this issue of adequate inventory and production capacity. Increased inventories, although politically unpopular when the commercial world is reducing them and budgets are being reduced, may be the watchword of the U.S. Army during the next decade of the post–Cold War era. A delicately balanced, highly efficient and interdependent agile manufacturing industrial base--if allowed to develop without the active cognizant and financially adequate involvement of the U.S. Army logistics community-- may be too fragile, or just too busy, to successfully respond to a random step function production requirement that a nearly simultaneous major regional contingency conflict requires.

Bibliography

Aces for Robot Agility. (1992, December). Manufacturing Engineering, 109, p. 22. (From ProQuest ABI/INFORM (R) Global Edition [abstract], Access No. 00656297)

Acquisition and Logistics. MAM-RC Phase IV Reference Book. (1995, June). Ft Lee, VA: U.S. Army Logistics Management College, p II-11, V1-V10.

Adaptive Robotic End-effector Handles Challenging Applications. (1993, June 1). Robotics World, 11, p. 10. (Summary from UnCover electronic database)

Adelsberger, Bernard. (1995, May 8). Budget Wants 20,000 More Active Duty Cuts. Army Times, 41, p 4.

Agility Forum: Call for Abstracts (1995). [Brochure] Call for Abstracts for the 5th Annual Agility Forum Conference. Conference Theme is: Becoming Agile by 2000: Ramping Up. Bethlehem, PA: Agility Forum of the Agile Manufacturing Enterprise Forum.

AMEF: Agile Manufacturing Enterprise Forum. (1994). [Brochure] Description of AMEF History and Objectives for Information Distribution. Bethlehem, PA: Agile Manufacturing Enterprise Forum.

Army Inventory: Opportunities Exist for Additional Reductions to Retail Level Inventories. (1994, June). [Report to the Chairman, Subcommittee on Readiness, Committee on Armed Services, House of Representatives] Washington, DC: General Accounting Office. (GAO/NSIAD-94-129)(DLSIE #LD092865A)(21 pages)

Army Regulation 220-1: Field Organizations Unit Status Reporting. (1993, July 31). Washington, DC: HQ, Department of the Army.

Army Regulation 750-1: Army Matériel Maintenance Policy and Retail Maintenance Operations. (1991, September). Washington, DC: HQ, Department of the Army.

Austin, Mike. (1994, Summer). Managing the U.S. Defense Industrial Base: A Strategic Imperative. Parameters, pp. 27-37. [Direct quote from Machine Design. (1992, February 20), p. 32.]

Bilikam, Robert. (1993, November). Trended Demand Economic Order Quantity

(EOQ) and Stratification of Levels. Dayton, OH: Defense Electronics Supply Center, Operations Research Office.

Blackwell, James. (1994, September 14). Tank-Automotive Seminar for The Army Industrial Base Assessment Model. [Read-Ahead Booklet] Washington, DC: Strategic Assessment Center, Science Applications International Corporation.

Bureau of Export Administration. (1986, July 18). Joint Logistics Commanders Bearing Study: Critical Technologies Washington, DC: Strategic Analysis Div. (NTIS No: PB93-192599/HDM) (167 pages)

Bureau of Export Administration. (1987, June 19). Joint Logistics Commanders Precision Optics Study: Critical Technologies. Washington, DC: Strategic Analysis Div. (NTIS No: PB93-192565/HDM) (169 pages)

Bureau of Export Administration. (1991, January). National Security Assessment of the U.S. Gear Industry: Critical Technologies. Washington, DC: Strategic Analysis Div. (NTIS No: PB93-192490/HDM) (157 pages)

Bureau of Export Administration. (1992, March). National Security Assessment of the Domestic and Foreign Subcontractor Base: A Study of Three U.S. Navy Weapon Systems: Critical Technologies. Washington, DC: Strategic Analysis Div. (NTIS No: PB93-183739/HDM) (179 pages)

Christensen, John. (1993, Spring). Generalized Emulation of Microcircuits: A Gem of an Idea. FCIM FOCUS, 3(2), 24-25.

Clem, Harold J. (1983). Mobilization Preparedness. Washington, DC: National Defense University.

Cohen, Martin; Kotkin, Meyer; and Kruse, Karl. (1990, January). Combat ASL [Technical Report, unnumbered]. Aberdeen Proving Ground, MD: Army Matériel Systems Analysis Activity, Inventory Research Office. (71 pages)

Compaq Still Tops. (1995, August 8). The News & Observer, p. 2D.

Coley, Douglas. (1995, January). Telephone conversation with Mr. Coley concerning the Fielded Vehicle Performance Data System (FVPDS) developed by TACOM to track parts. Mr. Cooley provided ship transport times. Warren, MI: U.S. Army Tank Automotive Command.

Correll, John T. and Nash, Colleen A. (1991, December). The Industrial Base

at War. The Air Force Magazine, pp. 52-56.

Culosi, Salvatore J. and Garner, David P. (1992, March). The PEACE Program: Production Expansion/Acceleration Capability Enhancement [Computer Program and Manual]. McLean, VA: Logistics Management Institute

DARCOM Pamphlet 750-5: Maintenance of Supplies and Equipment, Objective Determination of Failure Factors. (1983, April). Alexandria, VA: HQ, U.S. Army Matériel Development and Readiness Command.

Decker, O., Aquino, Joseph P., and Napier, Stephen D. (1992, April 28). Tracked and Wheeled Vehicles Industrial Sector Study. Alexandria, VA: American Defense Preparedness Association Independent Industrial Analysis Team and the Production Management Division, U.S. Army Tank-Automotive Command for the U.S. Army Matériel Command.

Department of the Army Pamphlet 710-2-1: Using Unit Supply System Manual Procedures. (1992, January). Washington, DC: HQ, Department of the Army.

Donath, Bob. (1993, June 21). The Marketing Millennium Begins in 2006. Marketing News, 27, pp. 13, 15.

Dove, Rick. (1992, December). The Factory America Net: CALS and the Agile Enterprise Community Presented as CALS EXPO '92: TRACK CC, Part 2 (Video). Washington, DC: National Security Industrial Association. (NTIS No: PB93-782118/HDM) (1 VHS video, color, 29 minutes)

Erickson, Richard F., and Hammond, Donald H. (1974). Description of Expected Failure Rates of Newly Acquired Components Prior to Steady State. [Master's Thesis]. Wright-Patterson AFB, OH: Air Force Institute of Technology.

Ettlie, J. (1992, October). Agility: the $500,000 Answer? Production, 104, p. 14.

Fast, Agile Six-axis Robot Combines AC Motors, New Control, Dual Bearings. (1987, February). American Machinist & Automated Manufacturing, 131, p. 31.

Field Manual 100-5, Operations. (1986). Washington, DC: HQ Department of the Army, p. 61.

Field Manual 101-5-1: Operational Terms and Symbols (1985, October 21). Washington, DC: HQ Department of the Army, pp. 1-43.

Field Manual 101-10-1/2: Staff Officers' Field Manual, Organizational, Technical, and Logistical Data Planning Factors (Volume 2). (1987, October 7). Washington, DC: HQ Department of the Army, pp. 2-165 and 2-177.

Evering, Vicki and Kwon, Jin. (1994, November). Two Major Regional Contingencies (MRCs) Sustainment. [Paper, Presented at the Army Operations Research Symposium XXXIII, Ft. Lee, VA.] Aberdeen Proving Ground, MD: U.S. Army Matériel Systems Analysis Activity.

Garcia, A. B., Glocke, R. P., and Johnson, N. P. (1994, March). Virtual Prototyping: Concept to Production. Fort Belvoir, VA: Defense Systems Management College Press.

Garner, D. P., Culosi, S. J., Bothwell, W. W., Edlund, M. E., and Jackson, M. G. (1992, May). Assessing the Adequacy of the Industrial Base: Final Report. Bethesda, MD: Logistics Management Institute; Alexandria, VA: Institute for Defense Analysis; Arlington, VA: The Analytic Sciences Corp.; Washington, DC: Distributed by Information Memorandum dated May 14, 1992, Assistant Secretary of the Army (Installations, Logistics and Environment). (NTIS No: AD-A264 954/9/HDM, DLSIE No. LD 092088A) (425 pages)

General Accounting Office. (1989, November). Industrial Base: Adequacy of Information on the U.S. Defense Industrial Base. (Report No: GAO/NSIAD-90-48). Washington, DC: National Security and International Affairs Div. (NTIS No: AD-A267 816/7/HDM) (20 pages)

General Accounting Office. (1991, January). Industrial Base: Significance of DOD's Foreign Dependence (Report No: GAO/NSIAD-91-93). Washington, DC: National Security and International Affairs Division [Report to the Chairman, Subcommittee on Technology and National Security, Joint Economic Committee, U.S. Congress]. (NTIS No: AD-A267 730/0/HDM) (26 pages).

General Accounting Office. (1991, April 16). Significance of DOD's Foreign Dependence. [Testimony] (Report No: GAO/T-NSIAD-91-20). Washington, DC: National Security and International Affairs Div. (NTIS No: AD-A268 050/2/HDM) (9 pages).

General Accounting Office. (1992, January). Operation Desert Storm: Early Performance Assessment of Bradley and Abrams (Report No: GAO/NSIAD-

92-94). Washington, DC: National Security and International Affairs Div.

General Accounting Office. (1992, December). National Security Issues (Report No: GAO/OCG-93-9TR). Washington, DC: National Security and International Affairs Div. (NTIS No: AD-A263 140/6/HDM) (43 pages)

General Accounting Office. (1993a, March). Defense Industrial Base: An Overview of an Emerging Issue (Report No: GAO/NSIAD-93-68). [Free market or managed industrial base required to meet national security needs? A GAO opinion] Washington, DC: National Security and International Affairs Div. (NTIS No: AD-A264 624/8/HDM) (16 pages)

General Accounting Office. (1993b, July). Industrial Base: Impact of Defense Downsizing on Selected Abrams Tank Subcontractors (Report No: GAO/NSIAD-93-214). Washington, DC: National Security and International Affairs Division [Report to the Chairman, Committee on Armed Services, House of Representatives]. (NTIS No: AD-A267 482/8/HDM) (11 pages)

Glashow, Jason. (1995, February 6). Tank Upgrade Funds Fall Short. Army Times, 28, p. 34.

Goldman, S. L. and Nagel, R. N. (1993). Management, Technology and Agility: The Emergence of a New Era in Manufacturing. International Journal of Technology Management, 8, pp. 18-38.

Graham, D. R., Kanter, H., Van Atta, R. H., Hoyler, H. M., and Nauta, J. (1993, January). Reconstitution and Defense Conversion (Report No: IDA-P-2813 and IDA/HQ-92-43225). Alexandria, VA: Institute for Defense Analysis. (NTIS No: AD-A266 287/2/HDM) (58 pages)

Graham, D., Dahlman C., and Gunkel, R. (1993, March 29). Towards Agile Logistics: Briefing for J4 Sponsors. [Slide presentation by authors during a conference on Agile Manufacturing at the Defense General Supply Center, Richmond, VA.] Alexandria, VA: Institute for Defense Analysis.

Hamel, Gary and Prahalad, C. K. (1989, May-June). "Strategic Intent." Harvard Business Review.

Hardy, D. E. (1993, March 30). Reconstitution: A Weak Link in U.S. Security [Study project]. Carlisle Barracks, PA: Army War College. (NTIS No: AD-A264 447/4/HDM) (72 pages)

Hennig, R. J. and Cusmina, T. A. (1990, December). Plant Equipment

Packages: Are they a Credible Deterrent to War. Master's thesis, Naval Postgraduate School, Monterey, CA. (NTIS No: AD-A246 523/5/HDM) (158 pages)

Holusha, John. (1994, May 25). Industry is Learning to Love Agility. The New York Times, pp. D1, D5 [Business Day].

Hudson, Neff. (1995, June 12). House Panel: Hold Army at 495,000. Army Times, 46, p. 3.

Industrial Base Support Study: Systems and Operational Analysis Support--Force and System Effectiveness Analysis. (1992, April 29). [Final Report]. Vector Research, Inc., Ann Arbor, MI.

Johnson, Ralph E. (1993, June). Stochastic Concepts Evaluation Model - Phase III (STOCEM-3). Technical Paper CAA-TP-93-2, U.S. Army Concepts Analysis Agency.

Joint Staff/DLA/GSA Agile Tactical Team Meeting (1994, 19-21 January). [Collection of slide presentations and team member package of materials] Alexandria, VA: Institute for Defense Analysis.

Jones, Edward R. (1991, March 4). Final Quick-Reaction Report on Budgeting for War Reserve Stocks in the Defense Logistics Agency (Project No DLA-0077.01 [Report No. 91-056 for Comptroller of the DOD and Director, DLA from the DOD Inspector General]. Arlington, VA: DOD Inspector General. (This letter report describes the process for WRS as part of the findings)

Kaitz, Edward M. and Jankowsky, Kurt. (1993, July). The Effects of a Scale-Down in Defense Budgets, Volume I. Ft. Belvoir, VA: Defense Systems Management College Press. (ISBN 0-16-041948-4)

Kanter, H. and Van Atta, R. H. (1993, February). Integrating Defense into the Civilian Technology and Industrial Base, (Report No: IDA-P-2801, and IDA/HQ-92-43007). Alexandria, VA: Institute for Defense Analyses. (NTIS No: AD-A266 286/4/HDM) (98 pages)

Kaplan, Alan J. (1990, August) [Technical Report]. Update of the VSL/EOQ Model. (DLSIE No. LD 085365A). Philadelphia, PA: U.S. Army Matériel Systems Analysis Activity, Inventory Research Office.

Kotkin, Meyer. (1994, September 29). [Telephone conversation with Mr. Kotkin.] Philadelphia: U.S. Army Matériel Systems Analysis Activity, Inventory

Analysis Office.

Laporte, G. (1991). Vehicle Routing Problem: An Overview of Exact and Approximate Algorithms (Publication no. 745). Montreal Univ. (Quebec). Centre de Recherche sur les Transports (Canada). (NTIS No: MIC-91-02933/HDM) (38 pages)

Leighton, L. D. (1992, April). Industrial Base Mobilization: Recommendations for Improvement Unheeded (Report No: NDU-ICAF-92-RS3C). Research report, Industrial College of the Armed Forces, Washington, DC. (NTIS No: AD-A262 291/8/HDM) (51 pages)

Levin, Doron P. (1994, November 15). Compaq PC Dominance Starts in Factory. The News & Observer, p. 5D.

Ligus, Richard G. (1990, September). The Agile Enterprise, Manufacturing Engineering, 105, p. 120.

Lopes, Peter F. (1992, November). CIM II: The Integrated Manufacturing Enterprise. Industrial Engineering, 24, p. 43-5.

Lund, J., Berg, R. and Replogle, C. (1993). Project AIR FORCE Analysis of the Air War in the Gulf: An Assessment of Strategic Airlift Operational Efficiency. Santa Monica, CA: RAND.

Matthews, William. (1995, January 9). Logistics Overhaul Faces Many Obstacles. Army Times, 24, p. 13.

Mazaarr, M. J., Snider, D. M., and Blackwell, J. A. (1993) Desert Storm: The Gulf War and What We Learned. Boulder, CO: Westview Press

Melius, M. S. (1991, May). Rapid Response Mobilization Indicator (Report No: DLA-91-P00249). Alexandria, VA: Defense Logistics Agency. (NTIS No: AD-A236 243/2/HDM) (68 pages)

Merritt, J. N. (1994, March-April). Army at Risk [Editorial]. AUSA News, 16, p. 4.

Miller, Don. (1994, October 20). Electronic mail response containing projected number of M1 Abrams series main battle tanks in the U.S. Army as of January 1996. Number of M1s will decrease and M1A2s increase as conversions are accomplished on a 1:1 ratio. Warren, MI: U.S. Army Armored Systems Modernization Program Executive Office.

Mintz, John. (1995, 22 October). Going Great Guns: U.S. Defense Companies are Merging, Cutting Workers and Closing Plants as Military Spending Declines. So Why are Their Stock Prices Heading for the Stratosphere? The Washington Post, pp. H1, H6.

Morrocco, J. D. and Fulghum, D. A. (1993, September 6). Saving industrial base key in bottom-up review. Aviation Week & Space Technology, 139, pp. 24-26.

Nagel, R. N. (1993, October 13). An Industry-Led Vision of 21st Century Competition: Agile Organizations and Virtual Companies are Emerging as a New Form of Competition as We Enter the 21st Century. [Slide presentation by author] Richmond, VA: Defense General Supply Center.

Nagel, R. N. and Dove, R. (1991a, November and reprinted 1992, March). 21st Century Manufacturing Enterprise Strategy, Volume 1: An Industry-Led View. Bethlehem, PA: Agile Manufacturing Enterprise Forum in cooperation with the Iacocca Institute, Lehigh University. (NTIS No: AD-A257 167/7/HDM) (66 pages)

Nagel, R. N. and Dove, R. (1991b, November and reprinted 1992, March). 21st Century Manufacturing Enterprise Strategy, Volume 2. Bethlehem, PA: Iacocca Inst., Lehigh University. (Copies available only from Iacocca Institute, Lehigh University., Harold S. Mohler Laboratory 200, Bethlehem, PA 18015.) (134 pages)

Naylor, Sean D. (1994, June 20). How the Review Hits the Army. Army Times, 47, p. 13.

Northrop Cuts Back. (1994, September 1994). News and Observer, p. 12C.

Papke, Brian. (1993, October). Speaking Out: Manufacturing Gets Ready for 21st Century. Tooling & Production, p. 90.

Paslaski, Gary. (1995, August 9). [Telephone conversation with Mr. Paslaski.] Warren, MI: U.S. Army Tank-Automotive Command.

Peters, Katherine McIntire. (1995, February 13). Army Budget Drops to $59.5 Billion. Army Times, 29, p. 3.

Perry, William J. (1994, June 24). Subject: Specifications & Standards - A New Way of Doing Business [Memorandum]. Washington, DC: Office of the Secretary of Defense.

Perry, William J. (1995, May 10). Subject: Use of Integrated Product and Process Development and Integrated Product Teams in DoD Acquisition [Memorandum]. Washington, DC: Office of the Secretary of Defense.

Pexton, Patrick. (1995, May 29). Analysts: Substitute Better Weapons for People. Army Times, 44, p. 3.

Porter, David L. (1992, June 19). Can the Defense Technology Industrial Base Meet Surge and Mobilization Requirements? Newport, RI: Naval War College, Department of Military Operations

Pritsker, A. A. B. (1986). Introduction to Simulation and SLAM II (3rd ed.). New York: John Wiley & Sons.

Program Management: Advanced Program Management Course 95-2. (1995, July). (pp. PM 721-5 - PM 721-9). [Reprinted text of speech by Secretary of Defense to National Contract Management Association, November 18, 1993] Ft. Belvoir, VA: Department of Defense Systems Management College.

Ray, Kay and Morris, Joel. (1994, July-August). Army Industrial Base Sector Surveys. Army Research, Development, and Acquisition Bulletin, pp. 9-10.

Richanbach, Paul H. and Bicksler, Barbara (1986, November). Industrial Surge and Force Sustainability [Includes documentation of "D-to-P" Computer Spreadsheet Model]. Alexandria, VA: Institute for Defense Analysis. (IDA Log No. HQ 86-31, DLSIE No. LD 079120A, DTIC No. AD-B121 761) (75 pages)

Rifkin, Glenn. (1994, Nov 8). Computerized Tailor Makes Levi's to Fit a Buyer's Curves. The News & Observer, pp. 1A, 6A.

Robillard, G. C. (1994, March). Wholesale Level Consumable Item Inventory Model for Non-stationary Demand Patterns. [Master's Thesis] Monterey, CA: Naval Postgraduate School.

Rogers, E. R. (1991, May 30). Sustaining Base: How Significant are the Shortcomings (Monograph). Fort Leavenworth, KS: Army Command and General Staff College. (NTIS No: AD-A243 338/1/HDM) (57 pages)

Ross, Sheldon M. (1989). Introduction to Probability Models. San Diego: Academic Press, Inc.

Ross, Sheldon M. (1990). A Course in Simulation. New York: Macmillan Publishing Company.

Schwartz, Bernard L. (1992). The Future of the U.S. Defense Industrial Base. Washington, DC: Foreign Policy Institute, The Paul H. Nitze School of Advanced International Studies.

Scivally, Franklin R. and McPeak, William S. , Jr. (1994, May/June). Collection of Industry Data Rates Below Par: Survey Reveals Many Second- and Third-tier Contractors are Giving Up on Defense Market. National DEFENSE, pp. 48-49.

Shamess, J. M. (1992, March 21). Preserving the U.S. Military Technological Edge: A Long-Term Military-Industrial-Economic Strategy to Expand the U.S. Military Technological Edge into the 21st Century. [Study project] Carlisle Barracks, PA: Army War College. (NTIS No: AD-A251 310/9/HDM) (62 pages)

Simberg, Henry and Evering, Vicki. (1995, April). Telephone conversations verified the use of coefficients to FFIV based on combat status. Aberdeen Proving Ground, MD: Army Matériel Systems Analysis Activity.

"SIMFACTORY II.5/SIMPROCESS." (1994, June 14) [Computer software, release 6.14, for Windows 3.1]. La Jolla, CA: CACI Products Company.

Simulation with SIMFACTORY II.5/SIMPROCESS. (1994). [Computer software manual, release 6.2]. La Jolla, CA: CACI Products Company.

Skibbie, L. F. (1994, January-February). Prudent Defense Base Blueprint Critical to U.S. Security in the 90s: Slimmed Down Military Force Structure Demands World Class Weapons Systems. Army Research, Development and Acquisition Bulletin, PB 70-94-1, HQ Department of the Army, pp. 10-11.

Stevenson, Burton [editor] (1967). The Home Book of Quotations, Classical and Modern [10th edition, revised, p. 2,041]. [This is the source for the quote by Benjamin Franklin on page ii.] New York: Dodd, Mead, and Company.

Syzdek, Mark A. (1994, April). Reducing Base Level Stocks by Revisiting the Economic Order Quantity Demand Model. Maxwell Air Force Base, AL: Air Force Logistics Management Agency. (AFLMA Final Report LS933431)

Taylor, Doria. (1995, February 27). The 10-division Army: Where It's Been, Where It's Going. Army Times, 31, p. 10.

Technical Manual 9-2350-276-BD: Battlefield Damage Assessment and Repair for Combat Vehicles. (1984, February). Washington, DC: HQ Department of the Army, p. 1-1.

Theater Capabilities Assessment Study. (1994, June 20). Bethesda, MD: U.S. Army Concepts Analysis Agency.

Tice, Jim. (1995, March 27). Too Little Money in '96 Budget for Modernization. Army Times, 35, p 17.

Training and Doctrine Command and Army Matériel Command Pamphlet 710-11, RAM Rational Report Handbook. (1985, Feb 1). Fort Monroe and Alexandria, VA: U.S. Army.

Triplett, William C., III. (1994, November 21). Time to Wake Up to the 'Real' Threat That China Presents [Opinion]. Army Times, 17, 39.

Triumph, Tribulation in the Sullivan Years. (1995, June 26). Army Times, 48, pp. 14-18.

U.S. Congress, Office of Technology Assessment. (1991, July). Redesigning Defense: Planning the Transition to the Future U.S. Defense Industrial Base (OTA-ISC-500). Washington, DC: U.S. Government Printing Office.

Valovic, T. (1992, June). Can High-speed Networks Help U.S. Companies Regain a Competitive Edge? Telecommunications, 26, p. 25-28.

Vawter, Roderick L. (1983). Industrial Mobilization: The Relevant History. Washington, DC: National Defense University

Velocci, A. L. Jr. (1993b, November 15). Perry Forges New Shape for Industry: Pentagon Official's Goal is to Recast a Defense Industrial Base that is Smaller but Healthier While Retaining Its Responsiveness to National Security Needs. Aviation Week & Space Technology, pp. 52-53, 56-57.

Youssef, Mohamed A. (1992 December). Agile Manufacturing: A Necessary Condition for Competing in Global Markets. Industrial Engineering, 24, pp. 18-20.

Zeller, Randel L. (1991). Responsive Industrial Support Exists. [Unpublished research paper]. Newport, RI: Naval War College, p. 28 as quoted in Porter, D. L. (1992, June). Can the Defense Technology Industrial Base Meet Surge and Mobilization Requirements: Final report. Newport, RI: Naval War

College, Dept. of Operations, p. 11.

Additional References

Announcing the 2nd National Conference on Agile Manufacturing: An Integrated System for Achieving Flexibility, Speed & Responsiveness. (1994). [Brochure] Conference information and registration advertisement for conference held May 23-24, 1994 in the Forum Hotel. Chicago: [Sponsored by the] International Quality and Productivity Center.

Atwood, C. L., McCarty, G. D., and Pardo, B. T. (1993). Integration of Rapid Prototyping Into Design and Manufacturing (Report No: SAND-93-0931C; CONF-9305176-1). Albuquerque, NM: Sandia National Labs. [Presented at Rapid Prototyping and Manufacturing '93 Conference and Exhibits, Dearborn, MI, 10-13 May 1993]. (NTIS No: DE93011554/HDM) (5 pages)

Beckwith, C. E., Smith, T. D., and Latiff, R. (1991, May). National Security and the Industrial Policy Debate: Modernizing Defense Manufacturing. [Paper] Carlisle Barracks, PA: Army War College. (NTIS No: AD-A246 619/1/HDM) (87 pages)

Beltramo, Michael N. (1994, March-April). How Affordable a Strong Defense? The Industrial Base is the Key. Program Manager, Vol XXII, No 2, pp. 28-30.

Brooke, Lindsay. (1993, August). Is Agile the Answer? Automotive Industries, 173, pp. 26-28.

Conver, S. K. (1993, March). Defense Industrial Base: Shaping the Downsizing. Armed Forces Journal International, 130, pp. 48-49.

Damian, Jacqueline. (1992, February) A Modest Proposal: 'Agile Manufacturing' Can Revive U.S. Competitiveness. Electronics, 65, p. 26.

Dees, R. F. and Williams, B. W. (1992, April) Watervliet Arsenal: Snapshot of Industrial Base Change (Report No: NDU-ICAF-92-G3). Research report, Industrial College of the Armed Forces, Washington, DC. (NTIS No: AD-A262 241/3/HDM) (77 pages)

Defense Systems Management College. (1993, January) Streamlining Defense Acquisition Laws. Chapter 7. Defense Trade and Cooperation. [Significant chapters from Streamlining Defense Acquisition Laws are published as separate documents.] Fort Belvoir, VA. (NTIS No: AD-P008 599/3/HDM) (186 pages)

Department of Defense Critical Technologies Plan for the Committees on Armed Services United States Congress. (1991, May). Washington, DC: Department of Defense. (NTIS No: AD-A234 900/9/HDM) (375 pages)

Florence, J. (1994, January-February). National Automotive Center Focuses on Agile Manufacturing. Army Research, Development and Acquisition Bulletin, PB 70-94-1. Washington, DC: HQ Department of the Army, pp. 12-14.

General Accounting Office. (1993, April). Army Inventory: Current Operating and War Reserve Requirements Can Be Reduced (Report No: GAO/NSIAD-93-119). [Report to the Secretary of Defense] Washington, DC: National Security and International Affairs Div. (DLSIE No: LD 091493A) (36 pages)

Graham, D. R., Tai, A. J., and Bicksler, B. A. (1993, January). Defense and the Economy (Report No: IDA-P-2810 and IDA/HQ-92-43206). Alexandria, VA: Institute for Defense Analysis. (NTIS No: AD-A266 288/0/HDM) (98 pages)

Hernandez, J. J. (1993, March). Comparative Analysis of Options for Preserving the Tank Industrial Base. [Master's thesis] Monterey, CA: Naval Postgraduate School. (NTIS No: AD-A264 952/3/HDM) (167 pages)

Japikse, David and Olsofka, Frank A. (1993, November 1). Agile Engineering Accelerates Design. Mechanical Engineering, 115, pp. 60-62. (From summary in UnCover electronic database.)

Japzon, E. (1991, November-December). The Army Industrial Modernization Incentives Program. Army Research, Development & Acquisition Bulletin, pp. 30-32.

Lein, R. A. [erroneously listed in NTIS database as Meyer, F. L.] (1992, April). Policy Recommendations to Improve Selected American Industrial Base Capabilities (Report No: NDU-ICAF-92-SP3). [Research report] Washington, DC: Industrial College of the Armed Forces. (NTIS No: AD-A262 040/9/HDM) (57 pages)

Lemire, Judith K. (1993). Battlefield Damage Assessment and Repair: Is Improvised Maintenance the Battlefield Solution to the Repair Parts Dilemma? (Monograph). Fort Leavenworth, KS: School of Advanced Military Studies, U.S. Army Command and General Staff College.

Less, Michael. (1992, December). Agile Partnership for Weapon System Modification through Integrated Data Strategy (IDS) Applications. Presented

as CALS EXPO '92: TRACK CC, Part 1 (Video). Washington, DC: National Security Industrial Association., sponsored by CALS Industry Steering Group. (NTIS No: PB93-782100/HDM) (1 VHS video, color, 28 minutes)

Ligus, Richard G. (1993, January). Methods to Help Reengineer Your Company for Improved Agility. Industrial Engineering, 25, pp. 58-59.

Loh, K. H. (1991, September) Modelling Strategic Strikes against Transportation Networks [Master's thesis]. Monterey, CA: Naval Postgraduate School. (NTIS No: AD-A246 898/1/HDM) (100 pages)

Mann, W. F. (1991, March). SABER: A Theater Level Wargame [Master's thesis]. Wright-Patterson AFB, OH: Air Force Inst. of Tech., School of Engineering. (NTIS No: AD-A238 825/4/HDM) (Report No: AFIT/GOR/ENS/91M-9)(238 pages)

Marzot, G. S. (1993, February). NetStat: A Probabilistic Network Connectivity Analysis Tool (Report No: M-93B0000034). Bedford, MA: MITRE Corp. (NTIS No: AD-A262 838/6/HDM) (107 pages)

Mason, L. G. (1991, April). Consumable Item Planning for Industrial Preparedness [Study project]. Carlisle Barracks, PA: Army War College. (NTIS No: AD-A237 863/6/HDM) (52 pages)

Mele, J. (1993, July). Team Spirit and Nimble Moves. Fleet Owner, 88, p. 132. (From ProQuest ABI/INFORM (R) Global Edition [abstract], Access number 00751925.)

Moore, J. (1994, April 11). DOD Kills JLSC; Cites Costs, Delays. Federal Computer Week, 8, pp. 1, 41.

Nagel, R. N. (1992). 21st Century Manufacturing Enterprise Strategy Report. Bethlehem, PA: Agile Manufacturing Enterprise Forum. (From abstract, Manufacturing Technology Information Analysis Center electronic database, Reference No. T1646306) (NTIS No: AD-A257 032/3/XAB) (49 pages)

Namias, S. (1989). Production and Operations Analysis. Homewood, IL: Irwin.

Napier, J. (1992, October). Industrial Base Program: Item Selection Indicator Analytical Enhancements; Final report (Report No: DLA-93-P20047). Alexandria, VA: Defense Logistics Agency. (NTIS No: AD-A260 206/8/HDM) (19 pages)

National Research Council. (1990, August). Industrial Preparedness: National Resource and Deterrent to War; Final report. Washington, DC: Commission on Engineering and Technical Systems. National Academy Press. (NTIS No: PB91-208322/HDM) (79 pages)

Neal, R. E. (1992, November). Enterprise Technologies Deployment for Agile Manufacturing (Report No: Y/DX-2150). Oak Ridge, TN: Department of Energy Y-12 Plant. (NTIS No: DE93013257/HDM) (25 pages)

Phillips, C. A. (1992, April 27) Network Destruction Problem (Extended Abstract) (Report No: SAND-92-0186C). Albuquerque, NM: Sandia National Labs. (NTIS No: DE92016171/HDM) (27 pages)

Port, O. and Carey, J. (1991, December 16). This is What the U.S. Must Do to Stay Competitive: Make Factories 'Agile,' Link Them by Computer--and Collaborate. Business Week, pp. 92, 94, 96.

Port, O. (1992, October 23). Moving Past the Assembly Line. Business Week [Industrial/Technology edition], pp. 177, 180.

Pourbabai, B., Blanc, J. P. C. and van der Duyn Schouten, F. A. (1992). Optimizing Flow Rates in a Queuing Network with Side Constraints (Report No: FEW-511). [Research memo] Tilburg Univ. (Netherlands): Dept. of Econometrics. (NTIS No: PB92-149996/HDM) (21 pages)

Power, N. J. (1993, July-August). Industrial Mobilization Preparedness. Army Logistician, PB 700-93-4 HQ Department of the Army, pp. 2-5.

Redesigning Defense: Planning the Transition to the Future U.S. Defense Industrial Base. (1991, July). (Report No: OTA-ISC-500). Washington, DC: Office of Technology Assessment. (NTIS No: PB91-220012/HDM) (127 pages)

Report of the Defense Science Board Task Force on Defense Acquisition Reform. (1993, July). Washington, DC: Office of the Under Secretary of Defense (Acquisition). (NTIS No: AD-A268 734/1/HDM) (43 pages)

In search of agile manufacturing. (1993, February). Manufacturing Engineering, 110, p. 24+.

Shandle, Jack. (1993, March 8). Sandia Labs Launches Agile Factory Program. Electronics, 66, p. 14.

Sheridan, J. H. (1993, April 19). Agile Manufacturing: Stepping Beyond Lean Production. Industry Week, 242, pp. 30-46.

Smyth, D. [Associated Press] (1993, November 28). Design, Manufacturing Institute Cuts Time, Cost. Raleigh, NC: The News and Observer, sec D, p. 2.

Special Task Force Created to Win 21st Century War. (1994, March-April). AUSA News, 16, p. 13.

Tank Parts, Off the Shelf. (1993, April 6). New York Times [editorial], sec A, p. 22, col 1. (From ProQuest - Newspaper Abstracts [CD-ROM], Access number 02391685)

U.S. Army Tank-Automotive Command. (1993, December 15). Tracked Vehicle Industrial Base (Mr. Kendall). Presentation provided to OSD Director of Tactical Systems. Warren, MI: Author.

U.S. Army Tank-Automotive Command, Production Management Division, AMSTA-IC. (1993, November 17). Tracked Vehicle Industrial Base Report for Mr. Frank Kendall, OSD, Director of Tactical Systems. Warren, MI: Author.

Varnado, F. (1993, March). Effects on Weapon Systems' Producibility of Suspending System Development After Advanced Technology Demonstration. [Master's thesis] Monterey, CA: Naval Postgraduate School. (NTIS No: AD-A263 440/0/HDM) (143 pages)

Vasilash, G. S. (1993, April). Manufacturing Agility: The Conference. Production, 105, pp. 58-63.

Velocci, A. L. Jr. (1993a, June 21). Executives Assail Impact of Depots on Industrial Base. Aviation Week & Space Technology, 138, pp. 69-71.

Weimer, G. (1992, March). America 2006: Manufacturing Leader or Loser? Controls & Systems, 39, p. 66.

West, Richard L. (1994, April). Short Rations for the Army. Army, 44, pp. 19-25.

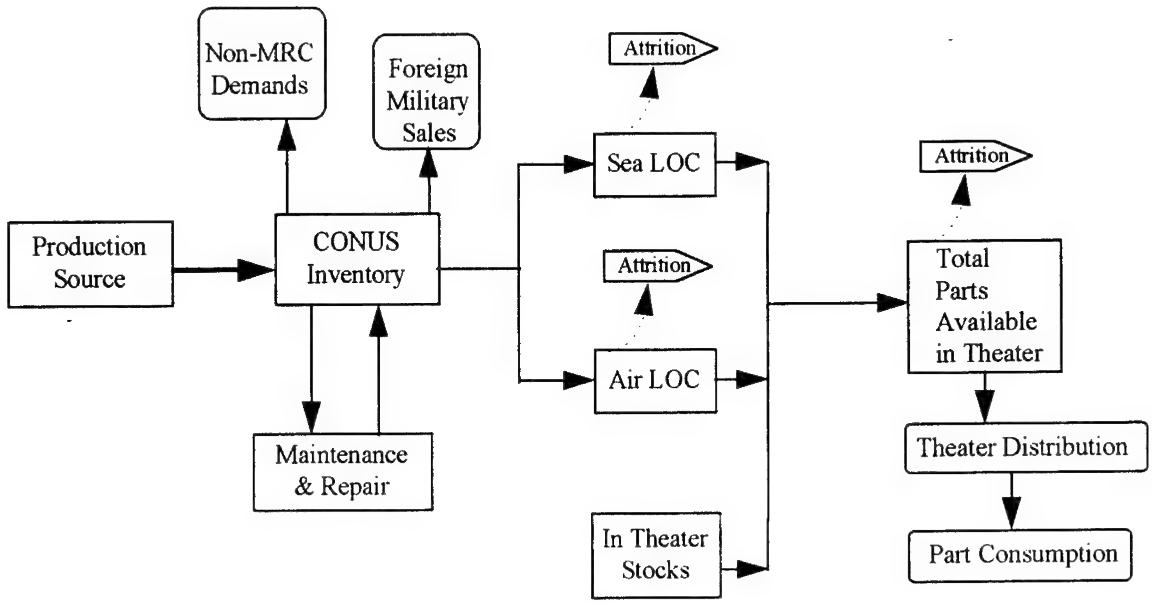
Appendices

Appendix A: A Brief Chronology of the Persian Gulf War Operations Desert Shield and Desert Storm

Date	Action or Event
Year: 1990	
August 2	Iraq invades Kuwait at 0200L (1900 EST)
August 6	King Fahd invites friendly forces to Saudi Arabia to reinforce his defenses
August 7	First U.S. units begin deploying to Saudi Arabia
August 12	101st Airborne Division and 11th Air Defense Artillery Brigade begin to deploy
October 23	U.S. troop strength in Gulf theater over 210,000
November 8	Additional U.S. forces designated for deployment include: 7th Corps HQ, 1st Armored Division, 3rd Armored Division, 2nd Armored Calvary Division (Forward), 2nd Corps Support Command, 1st Infantry Division (Mechanized)
November 29	United Nations Security Council Resolution #687 adopted, authorizes the use of all necessary means to uphold and implement previous resolutions if Iraq does not comply on or before January 15, 1991
Year: 1991	
January 16	Operation Desert Storm begins with air campaign at 1900 EST (0300, January 17, Riyadh)
January 18	U.S. troop strength in Gulf Theater over 450,000
February 23	Coalition forces begin ground offensive
February 27	Coalition forces suspend offensive operations
March 10	Redeployment of forces out of Gulf Theater begins

(Source: Garner, Culosi, Bothwell, Edlund, & Jackson, 1992, pp. IV-2-2)

Appendix B: D-to-P Part Flow



Appendix C: Tank Unit Deployment Schedule & Combat Status in the Northeast Asia Scenario

DAY 3 (2<TIME<=3)
*Start 30-1, Status Reserve=4
*Start 30-2, Status Reserve=4
*Start 31-1, Status Reserve=4
*Start 31-2, Status Reserve=4

DAY 13 (12<TIME<=13)
*Chg Status 30-1 Reduced=3
*Chg Status 30-2 Reduced=3
*Chg Status 31-1 Reduced=3
*Chg Status 31-2 Reduced=3

DAY 18 (17<TIME<=18)
*Chg Status 30-1 Moderate=2
*Chg Status 30-2 Moderate=2
*Chg Status 31-1 Moderate=2
*Chg Status 31-2 Moderate=2

DAY 21 (20<TIME<=21)
*Chg Status 30-1 Reduced=3
*Chg Status 30-2 Reduced=3
*Chg Status 31-1 Reduced=3
*Chg Status 31-2 Reduced=3

DAY 57 (56<TIME<=57)
*Chg Status 30-1 Moderate=2
*Chg Status 30-2 Moderate=2
*Chg Status 31-1 Moderate=2
*Chg Status 31-2 Moderate=2

DAY 61 (60<TIME<=61)
*Chg Status 30-1 Reduced=3
*Chg Status 30-2 Reduced=3
*Chg Status 31-1 Reduced=3
*Chg Status 31-2 Reduced=3

DAY 80 (79<TIME<=80)
*Chg Status 30-1 Moderate=2
*Chg Status 30-2 Moderate=2
*Chg Status 31-1 Moderate=2
*Chg Status 31-2 Moderate=2

DAY 81 (80<TIME<=81)
*Chg Status 30-1 Reduced=3
*Chg Status 30-2 Reduced=3
*Chg Status 31-1 Reduced=3
*Chg Status 31-2 Reduced=3

DAY 90 (89<TIME<=90)
*Chg Status 30-1 Moderate=2
*Chg Status 30-2 Moderate=2
*Chg Status 31-1 Moderate=2
*Chg Status 31-2 Moderate=2

DAY 91 (90<TIME<=91)
*Chg Status 30-1 Reduced=2
*Chg Status 30-2 Reduced=2
*Chg Status 31-1 Reduced=2
*Chg Status 31-2 Reduced=2

DAY 97 (96<TIME<=97)
*Start 43-S Status Reserve=4

DAY 99 (98<TIME<=99)
*Start 39-S, Status Reserve=4

DAY 100 (99<TIME<=100)
*Start 40-1, Status Reserve=4
*Start 40-2, Status Reserve=4

DAY 103 (102<TIME<=103)
*Start 44-S, Status Reserve=4
*Start 45-S, Status Reserve=4

DAY 104 (103<TIME<=104)
*Start 41-S, Status Reserve=4

DAY 105 (104<TIME<=105)
*Chg Status 39-S Reduced=3
*Chg Status 40-1 Reduced=3
*Chg Status 40-2 Reduced=3
*Chg Status 41-S Reduced=3

DAY 107 (106<TIME<=107)
*Chg Status 39-S Moderate=2
*Chg Status 43-S Reduced=3
*Chg Status 40-1 Moderate=2
*Chg Status 40-2 Moderate=2
*Chg Status 41-S Moderate=2
*Chg Status 44-S Reduced=3
*Chg Status 45-S Reduced=3

DAY 109 (108<TIME<=109)
*Start 32-S, Status Reduced=3
(Stays there)

DAY 110 (109<TIME<=110)
*Chg Status 39-S Intense=1
*Chg Status 43-S Moderate=2
*Chg Status 40-1 Intense=1
*Chg Status 40-2 Intense=1
*Chg Status 41-S Intense=1
*Chg Status 44-S Moderate=2
*Chg Status 45-S Moderate=2

DAY 111 (110<TIME<=111)
*Chg Status 39-S Reduced=3
*Chg Status 43-S Reduced=3
*Chg Status 40-1 Reduced=3
*Chg Status 40-2 Reduced=3
*Chg Status 41-S Reduced=3
*Chg Status 44-S Reduced=3
*Chg Status 45-S Reduced=3

DAY 115 (114<TIME<=115)
*Chg Status 39-S Moderate=2
*Chg Status 40-1 Moderate=2
*Chg Status 40-2 Moderate=2
*Chg Status 41-S Moderate=2

DAY 120 (119<TIME<=120)
*Chg Status 43-S Moderate=2
*Chg Status 44-S Moderate=2
*Chg Status 45-S Moderate=2

DAY 121 (120<TIME<=121)
*Chg Status 39-S Moderate=2
*Chg Status 43-S Reduced=3
*Chg Status 40-1 Reduced=3
*Chg Status 40-2 Reduced=3
*Chg Status 41-S Reduced=3
*Chg Status 44-S Reduced=3
*Chg Status 45-S Reduced=3

DAY 130 (129<TIME<= 130)
*Chg Status 39-S Reduced=3
*Chg Status 40-1 Moderate=2
*Chg Status 40-2 Moderate=2
*Chg Status 41-S Moderate=2
*Start 94-S, Status Moderate=2
*Start 77-1, Status Moderate=2
*Start 77-2, Status Moderate=2

DAY 131(130<TIME<=131)
*Chg Status 41-S Reduced=3
*Chg Status 94-S Reduced=3
*Start 77-1, Status Reduced=2
*Start 77-2, Status Reduced=2

DAY 135 (134<TIME<=135)
*Chg Status 43-S Moderate=2
*Chg Status 44-S Moderate=2
*Chg Status 45-S Moderate=2

DAY 136 (135<TIME<=136)
*Chg Status 43-S Reduced=3
*Chg Status 44-S Reduced=3
*Chg Status 45-S Reduced=3

DAY 140(139<TIME<=140)
*Chg Status 43-S Moderate=2
*Chg Status 44-S Moderate=2
*Chg Status 45-S Moderate=2

DAY 141 (140<TIME<=141)
*Chg Status 43-S Reduced=3
*Chg Status 44-S Reduced=3
*Chg Status 45-S Reduced=3

DAY 150 (149<TIME<=150)
END OF NEA Major Regional Conflict

Appendix D: Tank Unit Deployment Schedule & Combat Status in the Southwest Asia Scenario

DAY 8 (7<TIME<=8)
- *Start 47-1, Status Reserve=4
- *Start 47-2, Status Reserve=4

DAY 17 (16<TIME<=17)
- *Start 12-1, Status Reserve=4
- *Start 12-2, Status Reserve=4

DAY 21(20<TIME<=21)
- *Start 13-1, Status Reserve=4
- *Start 13-2, Status Reserve=4

DAY 26(25<TIME<=26)
- *Start 48-Single, Status Reserve=4

DAY 27(26<TIME<=27)
- *Start 14-Single, Status Reserve=4
- *Start 49-Single, Status Reserve=4

DAY 31 (30<TIME<=31)
- *Chg Status 47-1 Reduced=3
- *Chg Status 47-2 Reduced=3
- *Chg Status 12-1 Reduced=3
- *Chg Status 12-2 Reduced=3
- *Chg Status 13-1 Reduced=3
- *Chg Status 13-2 Reduced=3
- *Chg Status 14-Single Reduced=3
- *Chg Status 48-Single Reduced=3
- *Chg Status 49-Single Reduced=3

DAY 87 (86<TIME<=87)
- *Start 26-1, Status Reserve=4
- *Start 26-2, Status Reserve=4

DAY 91 (90<TIME<=91)
- *Start 35-Single, Status Reserve=4

DAY 92 (91<TIME<=92)
- *Start 34-Single, Status Reserve=4

DAY 93 (92<TIME<=93)
- *Start 27-1, Status Reserve=4
- *Start 27-2, Status Reserve=4

DAY 96(95<TIME<=96
- *Start 18-Single, Status Reserve=4

DAY 97(96<TIME<=97)
- *Start 17-1, Status Reserve=4
- *Start 17-2, Status Reserve=4

DAY 99 (98<TIME<=99)
- *Start 81-Single, Status Reserve=4

DAY 101 (100<TIME<=101)
- *Start 19-Single, Status Reserve=4
- *Start 36-Single, Status Reserve=4

DAY 102 (101<TIME<102)
- *Start 37-Single, Status Reserve=4

DAY 103 (102<TIME<=103)
- *Start 50-Single, Status Reduced=3

DAY 104 (103<TIME<=104)
- *Chg Status 12-1 Moderate=2
- *Chg Status 12-2 Moderate=2
- *Chg Status 13-1 Moderate=2
- *Chg Status 13-2 Moderate=2
- *Chg Status 14-Single Moderate=2
- *Chg Status 18-Single Reduced=3
- *Start 82-Single, Status Reserve=4

DAY 106 (105<TIME<=106)
- *Chg Status 12-1 Reduced=3
- *Chg Status 12-2 Reduced=3
- *Chg Status 13-1 Reduced=3
- *Chg Status 13-2 Reduced=3
- *Chg Status 14-Single Reduced=3
- *Chg Status 18-Single Reserve=4
- *Chg Status 34-Single Reduced=3
- *Chg Status 35-Single Reduced=3
- *Chg Status 36-Single Reduced=3
- *Chg Status 37-Single Reduced=3

DAY 107 (106<TIME<=107)
- *Chg Status 81-Single Reduced=3
- *Start 28-Single, Status Reserve=4

DAY 109 (108<TIME<=109)
- *Chg Status 12-1 Moderate=2
- *Chg Status 12-2 Moderate=2
- *Chg Status 13-1 Moderate=2
- *Chg Status 13-2 Moderate=2
- *Chg Status 14-Single Moderate=2
- *Chg Status 17-1 Reduced=3
- *Chg Status 17-2 Reduced=3
- *Chg Status 19-Single Reduced=3
- *Chg Status 82-Single Reduced=3

DAY 111 (110<TIME<=111)
- *Chg Status 12-1 Reduced=3
- *Chg Status 12-2 Reduced=3
- *Chg Status 13-1 Reduced=3
- *Chg Status 13-2 Reduced=3
- *Chg Status 14-Single Reduced=3
- *Chg Status 17-1 Reserve=4
- *Chg Status 17-2 Reserve=4
- *Chg Status 19-Single Reserve=4

DAY 114 (113<TIME<=114)
- *Chg Status 26-1 Reduced=3
- *Chg Status 26-2 Reduced=3
- *Chg Status 27-1 Reduced=3
- *Chg Status 27-2 Reduced=3
- *Chg Status 28-Single Reduced=3

DAY 117 (116<TIME<=117)
- *Start 15-1, Status Reduced=3
- *Start 15-2, Status Reduced=3

DAY 121 (120<TIME<=121)
- *Start 20-Single, Status Reserve=4

DAY 125 (124<TIME<=125)
END of SWA Major Regional Conflict

Appendix E: List of Unit Identifications

Tank Battalions Designated for Deployment in SWA	Tank Battalions Designated for Deployment to NEA
BN 12-1	BN 30-1
BN 12-2	BN 30-2
BN 13-1	BN 31-1
BN 13-2	BN 31-2
BN 14-S	BN 32-S
BN 15-1	BN 39-S
BN 15-2	BN 40-1
BN 17-1	BN 40-2
BN 17-2	BN 41-S
BN 18-S	BN 43-S
BN 19-S	BN 44-S
BN 20-S	BN 45-S
BN 26-1	BN 77-1
BN 26-2	BN 77-2
BN 27-1	BN 94-S*
BN 27-2	
BN 28-S	
BN 34-S	
BN 35-S	
BN 36-S	
BN 37-S	
BN 47-1	
BN 47-2	
BN 48-S	
BN 49-S	
BN 50-S	
BN 81-S	*Armored Cavalry Unit
BN 82-S	

Appendix F: Representative Repair Part Profile Mesh

		Failure Factors			Cumulative SWA Failure Factors per (vehicle-day)				Cumulative NEA Failure Factors per (vehicle-day)			
Part	FFI	FFII	SWA FFIV	NEA FFIV	Reserve	Reduced	Moderate	Intense	Reserve	Reduced	Moderate	Intense
AG1	20	20	0	0	0.000548	0.000548	0.000548	0.000548	0.000548	0.000548	0.000548	0.000548
AG2	20	20	0	10	0.000548	0.000548	0.000548	0.000548	0.000548	0.000767	0.000822	0.000932
AG3	20	20	0	20	0.000548	0.000548	0.000548	0.000548	0.000548	0.000986	0.001096	0.001315
AG4	20	20	0	40	0.000548	0.000548	0.000548	0.000548	0.000548	0.001425	0.001644	0.002082
AG5	20	20	0	100	0.000548	0.000548	0.000548	0.000548	0.000548	0.002740	0.003288	0.004384
AG6	20	20	10	0	0.000548	0.000767	0.000822	0.000932	0.000548	0.000548	0.000548	0.000548
AG7	20	20	10	10	0.000548	0.000767	0.000822	0.000932	0.000548	0.000767	0.000822	0.000932
AG8	20	20	10	20	0.000548	0.000767	0.000822	0.000932	0.000548	0.000986	0.001096	0.001315
AG9	20	20	10	40	0.000548	0.000767	0.000822	0.000932	0.000548	0.001425	0.001644	0.002082
AG10	20	20	10	100	0.000548	0.000767	0.000822	0.000932	0.000548	0.002740	0.003288	0.004384
AG11	20	20	20	0	0.000548	0.000986	0.001096	0.001315	0.000548	0.000548	0.000548	0.000548
AG12	20	20	20	10	0.000548	0.000986	0.001096	0.001315	0.000548	0.000767	0.000822	0.000932
AG13	20	20	20	20	0.000548	0.000986	0.001096	0.001315	0.000548	0.000986	0.001096	0.001315
AG14	20	20	20	40	0.000548	0.000986	0.001096	0.001315	0.000548	0.001425	0.001644	0.002082
AG15	20	20	20	100	0.000548	0.000986	0.001096	0.001315	0.000548	0.002740	0.003288	0.004384
AG16	20	20	40	0	0.000548	0.001425	0.001644	0.002082	0.000548	0.000548	0.000548	0.000548
AG17	20	20	40	10	0.000548	0.001425	0.001644	0.002082	0.000548	0.000767	0.000822	0.000932
AG18	20	20	40	20	0.000548	0.001425	0.001644	0.002082	0.000548	0.000986	0.001096	0.001315
AG19	20	20	40	40	0.000548	0.001425	0.001644	0.002082	0.000548	0.001425	0.001644	0.002082
AG20	20	20	40	100	0.000548	0.001425	0.001644	0.002082	0.000548	0.002740	0.003288	0.004384
AG21	20	20	100	0	0.000548	0.002740	0.003288	0.004384	0.000548	0.000548	0.000548	0.000548
AG22	20	20	100	10	0.000548	0.002740	0.003288	0.004384	0.000548	0.000767	0.000822	0.000932
AG23	20	20	100	20	0.000548	0.002740	0.003288	0.004384	0.000548	0.000986	0.001096	0.001315
AG24	20	20	100	40	0.000548	0.002740	0.003288	0.004384	0.000548	0.001425	0.001644	0.002082
AG25	20	20	100	100	0.000548	0.002740	0.003288	0.004384	0.000548	0.002740	0.003288	0.004384
AG26	20	40	0	0	0.001096	0.001096	0.001096	0.001096	0.001096	0.001096	0.001096	0.001096
AG27	20	40	0	10	0.001096	0.001096	0.001096	0.001096	0.001096	0.001315	0.001370	0.001479
AG28	20	40	0	20	0.001096	0.001096	0.001096	0.001096	0.001096	0.001534	0.001644	0.001863
AG29	20	40	0	40	0.001096	0.001096	0.001096	0.001096	0.001096	0.001973	0.002192	0.002630
AG30	20	40	0	100	0.001096	0.001096	0.001096	0.001096	0.001096	0.003288	0.003836	0.004932
AG31	20	40	10	0	0.001096	0.001315	0.001370	0.001479	0.001096	0.001096	0.001096	0.001096
AG32	20	40	10	10	0.001096	0.001315	0.001370	0.001479	0.001096	0.001315	0.001370	0.001479
AG33	20	40	10	20	0.001096	0.001315	0.001370	0.001479	0.001096	0.001534	0.001644	0.001863
AG34	20	40	10	40	0.001096	0.001315	0.001370	0.001479	0.001096	0.001973	0.002192	0.002630
AG35	20	40	10	100	0.001096	0.001315	0.001370	0.001479	0.001096	0.003288	0.003836	0.004932
AG36	20	40	20	0	0.001096	0.001534	0.001644	0.001863	0.001096	0.001096	0.001096	0.001096
AG37	20	40	20	10	0.001096	0.001534	0.001644	0.001863	0.001096	0.001315	0.001370	0.001479
AG38	20	40	20	20	0.001096	0.001534	0.001644	0.001863	0.001096	0.001534	0.001644	0.001863
AG39	20	40	20	40	0.001096	0.001534	0.001644	0.001863	0.001096	0.001973	0.002192	0.002630
AG40	20	40	20	100	0.001096	0.001534	0.001644	0.001863	0.001096	0.003288	0.003836	0.004932
AG41	20	40	40	0	0.001096	0.001973	0.002192	0.002630	0.001096	0.001096	0.001096	0.001096
AG42	20	40	40	10	0.001096	0.001973	0.002192	0.002630	0.001096	0.001315	0.001370	0.001479
AG43	20	40	40	20	0.001096	0.001973	0.002192	0.002630	0.001096	0.001534	0.001644	0.001863
AG44	20	40	40	40	0.001096	0.001973	0.002192	0.002630	0.001096	0.001973	0.002192	0.002630
AG45	20	40	40	100	0.001096	0.001973	0.002192	0.002630	0.001096	0.003288	0.003836	0.004932
AG46	20	40	100	0	0.001096	0.003288	0.003836	0.004932	0.001096	0.001096	0.001096	0.001096
AG47	20	40	100	10	0.001096	0.003288	0.003836	0.004932	0.001096	0.001315	0.001370	0.001479

AG48	20	40	100	20	0.001096	0.003288	0.003836	0.004932	0.001096	0.001534	0.001644	0.001863
AG49	20	40	100	40	0.001096	0.003288	0.003836	0.004932	0.001096	0.001973	0.002192	0.002630
AG50	20	40	100	100	0.001096	0.003288	0.003836	0.004932	0.001096	0.003288	0.003836	0.004932
AG51	20	60	0	0	0.001644	0.001644	0.001644	0.001644	0.001644	0.001644	0.001644	0.001644
AG52	20	60	0	10	0.001644	0.001644	0.001644	0.001644	0.001644	0.001863	0.001918	0.002027
AG53	20	60	0	20	0.001644	0.001644	0.001644	0.001644	0.001644	0.002082	0.002192	0.002411
AG54	20	60	0	40	0.001644	0.001644	0.001644	0.001644	0.001644	0.002521	0.002740	0.003178
AG55	20	60	0	100	0.001644	0.001644	0.001644	0.001644	0.001644	0.003836	0.004384	0.005479
AG56	20	60	10	0	0.001644	0.001863	0.001918	0.002027	0.001644	0.001644	0.001644	0.001644
AG57	20	60	10	10	0.001644	0.001863	0.001918	0.002027	0.001644	0.001863	0.001918	0.002027
AG58	20	60	10	20	0.001644	0.001863	0.001918	0.002027	0.001644	0.002082	0.002192	0.002411
AG59	20	60	10	40	0.001644	0.001863	0.001918	0.002027	0.001644	0.002521	0.002740	0.003178
AG60	20	60	10	100	0.001644	0.001863	0.001918	0.002027	0.001644	0.003836	0.004384	0.005479
AG61	20	60	20	0	0.001644	0.002082	0.002192	0.002411	0.001644	0.001644	0.001644	0.001644
AG62	20	60	20	10	0.001644	0.002082	0.002192	0.002411	0.001644	0.001863	0.001918	0.002027
AG63	20	60	20	20	0.001644	0.002082	0.002192	0.002411	0.001644	0.002082	0.002192	0.002411
AG64	20	60	20	40	0.001644	0.002082	0.002192	0.002411	0.001644	0.002521	0.002740	0.003178
AG65	20	60	20	100	0.001644	0.002082	0.002192	0.002411	0.001644	0.003836	0.004384	0.005479
AG66	20	60	40	0	0.001644	0.002521	0.002740	0.003178	0.001644	0.001644	0.001644	0.001644
AG67	20	60	40	10	0.001644	0.002521	0.002740	0.003178	0.001644	0.001863	0.001918	0.002027
AG68	20	60	40	20	0.001644	0.002521	0.002740	0.003178	0.001644	0.002082	0.002192	0.002411
AG69	20	60	40	40	0.001644	0.002521	0.002740	0.003178	0.001644	0.002521	0.002740	0.003178
AG70	20	60	40	100	0.001644	0.002521	0.002740	0.003178	0.001644	0.003836	0.004384	0.005479
AG71	20	60	100	0	0.001644	0.003836	0.004384	0.005479	0.001644	0.001644	0.001644	0.001644
AG72	20	60	100	10	0.001644	0.003836	0.004384	0.005479	0.001644	0.001863	0.001918	0.002027
AG73	20	60	100	20	0.001644	0.003836	0.004384	0.005479	0.001644	0.002082	0.002192	0.002411
AG74	20	60	100	40	0.001644	0.003836	0.004384	0.005479	0.001644	0.002521	0.002740	0.003178
AG75	20	60	100	100	0.001644	0.003836	0.004384	0.005479	0.001644	0.003836	0.004384	0.005479
AG76	20	120	0	0	0.003288	0.003288	0.003288	0.003288	0.003288	0.003288	0.003288	0.003288
AG77	20	120	0	10	0.003288	0.003288	0.003288	0.003288	0.003288	0.003507	0.003562	0.003671
AG78	20	120	0	20	0.003288	0.003288	0.003288	0.003288	0.003288	0.003726	0.003836	0.004055
AG79	20	120	0	40	0.003288	0.003288	0.003288	0.003288	0.003288	0.004164	0.004384	0.004822
AG80	20	120	0	100	0.003288	0.003288	0.003288	0.003288	0.003288	0.005479	0.006027	0.007123
AG81	20	120	10	0	0.003288	0.003507	0.003562	0.003671	0.003288	0.003288	0.003288	0.003288
AG82	20	120	10	10	0.003288	0.003507	0.003562	0.003671	0.003288	0.003507	0.003562	0.003671
AG83	20	120	10	20	0.003288	0.003507	0.003562	0.003671	0.003288	0.003726	0.003836	0.004055
AG84	20	120	10	40	0.003288	0.003507	0.003562	0.003671	0.003288	0.004164	0.004384	0.004822
AG85	20	120	10	100	0.003288	0.003507	0.003562	0.003671	0.003288	0.005479	0.006027	0.007123
AG86	20	120	20	0	0.003288	0.003726	0.003836	0.004055	0.003288	0.003288	0.003288	0.003288
AG87	20	120	20	10	0.003288	0.003726	0.003836	0.004055	0.003288	0.003507	0.003562	0.003671
AG88	20	120	20	20	0.003288	0.003726	0.003836	0.004055	0.003288	0.003726	0.003836	0.004055
AG89	20	120	20	40	0.003288	0.003726	0.003836	0.004055	0.003288	0.004164	0.004384	0.004822
AG90	20	120	20	100	0.003288	0.003726	0.003836	0.004055	0.003288	0.005479	0.006027	0.007123
AG91	20	120	40	0	0.003288	0.004164	0.004384	0.004822	0.003288	0.003288	0.003288	0.003288
AG92	20	120	40	10	0.003288	0.004164	0.004384	0.004822	0.003288	0.003507	0.003562	0.003671
AG93	20	120	40	20	0.003288	0.004164	0.004384	0.004822	0.003288	0.003726	0.003836	0.004055
AG94	20	120	40	40	0.003288	0.004164	0.004384	0.004822	0.003288	0.004164	0.004384	0.004822
AG95	20	120	40	100	0.003288	0.004164	0.004384	0.004822	0.003288	0.005479	0.006027	0.007123
AG96	20	120	100	0	0.003288	0.005479	0.006027	0.007123	0.003288	0.003288	0.003288	0.003288
AG97	20	120	100	10	0.003288	0.005479	0.006027	0.007123	0.003288	0.003507	0.003562	0.003671
AG98	20	120	100	20	0.003288	0.005479	0.006027	0.007123	0.003288	0.003726	0.003836	0.004055
AG99	20	120	100	40	0.003288	0.005479	0.006027	0.007123	0.003288	0.004164	0.004384	0.004822
AG 100	20	120	100	100	0.003288	0.005479	0.006027	0.007123	0.003288	0.005479	0.006027	0.007123

Appendix G: Configuring the Simulation Model for Objectives

I. General Parameters.

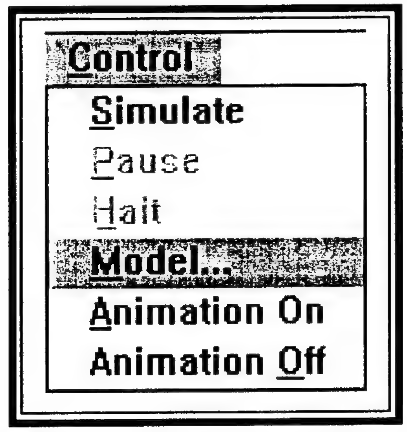


Figure G-1: Control Menu

General simulation model settings are entered in the **MODEL PARAMETERS** window. The path to the **MODEL PARAMETERS** window is found from the main window by selecting **CONTROL** and then **MODEL** as shown in Figure G-1. The **MODEL PARAMETERS** window contains four boxes: Simulation Control, Report Control, Animation Control, and

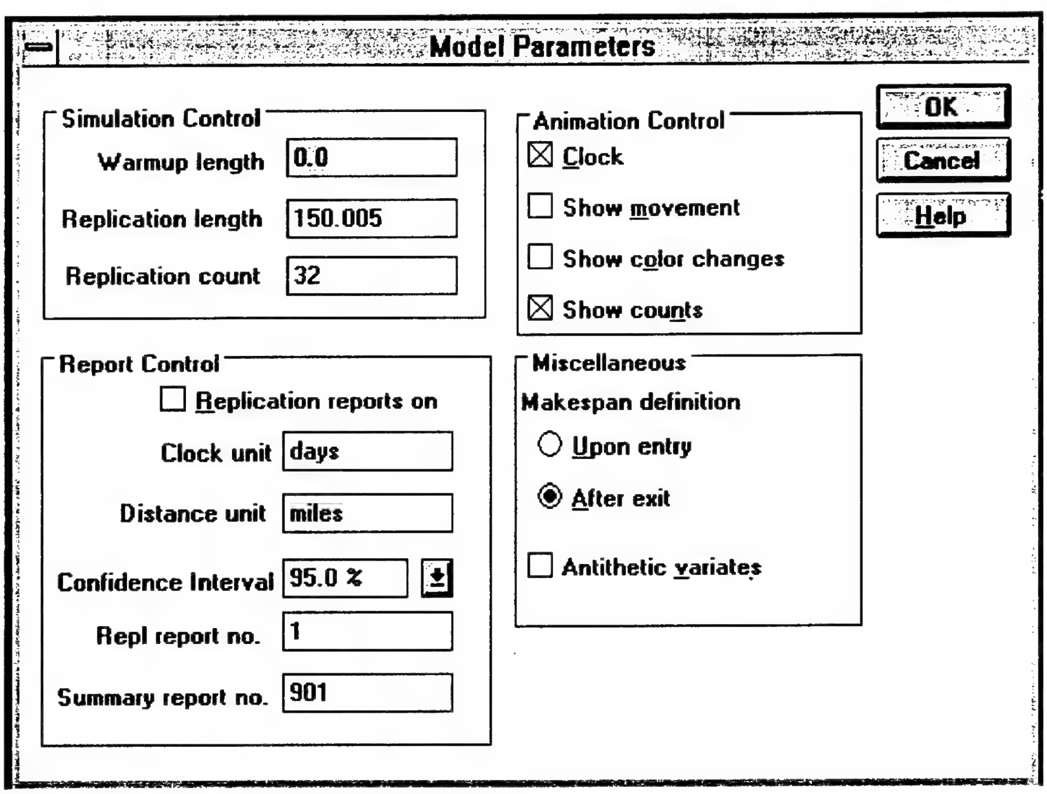


Figure G-2: Model Parameters Menu

Miscellaneous in which information may be entered. The **MODEL PARAMETERS** window as used in Objective 1 runs is show in Figure G-2. The **REPLICATION LENGTH** may be set to allow scenarios of any total length from 1 to 170 days. Simulations of longer length will require additional programming. An additional fractional part of a day, 0.005, is added to the desired replication length to insure that data collection is not accidentally truncated on the last day of the scenario. For the scenario demonstrated, the **REPLICATION COUNT** is set to 32 iterations and the **CONFIDENCE INTERVAL** calculation set to 95%. The animation control block as shown has all options except the clock and counts turned off to decrease the execution time of each iteration. Turning the animation off during production simulation runs decreases the execution time significantly.

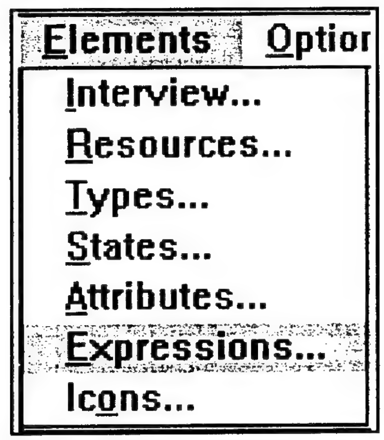


Figure G-3: Expressions Menu

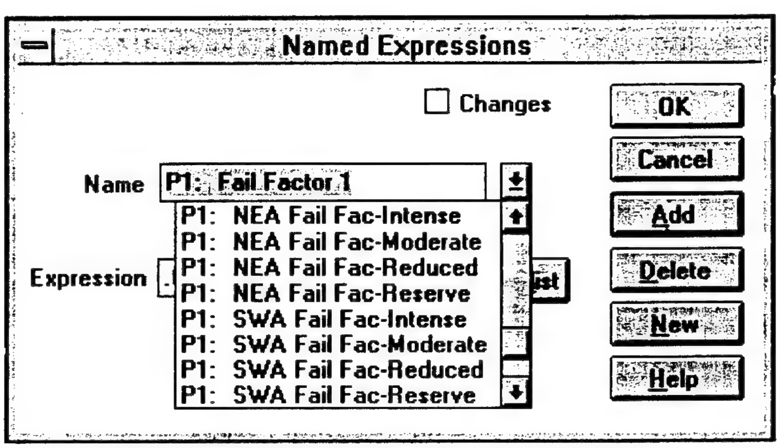


Figure G-4: Failure Factor Names

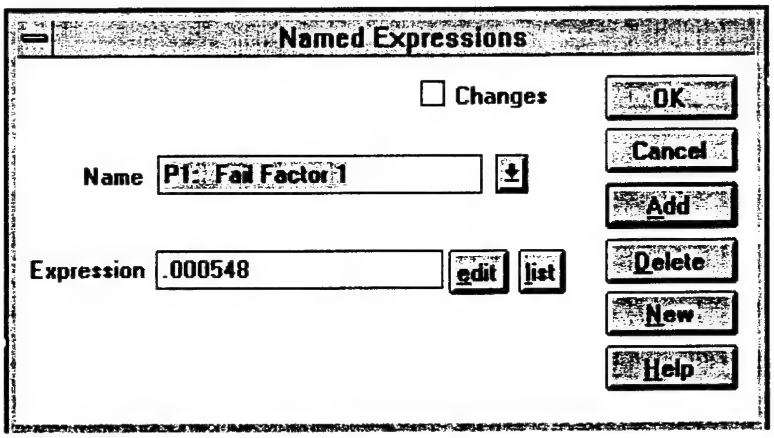


Figure G-5: Failure Factor I Datum Entry

Failure factors are entered as expressions that are referenced for part failure calculations during the simulation. The path to the NAMED EXPRESSIONS window from the main window is highlighted in Figure G-3. The failure factors are listed in the model by the names as shown in Figure G-4. A sample data entry is shown in Figure G-5. The representative repair part failure factor values for these variables are profiled in Appendix F.

Individual instances of the model for each repair part that is to be analyzed can be produced and then executed by the software in batch mode. Simply select Batch Run as indicated in Figure G-6 and highlight all of the models to be executed. They will be executed sequentially until all are runs are complete.

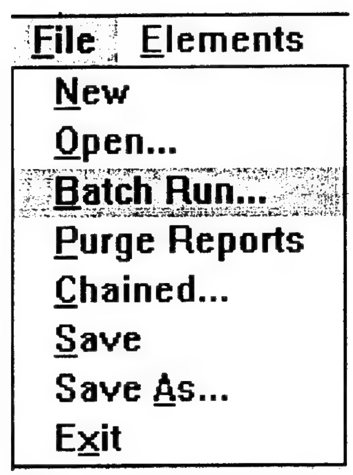


Figure G-6: Batch Menu

II. Model Speed Modifications for Objective 1.

The general simulation model developed and demonstrated for evaluating

the operational readiness of given combinations of inventory and production as required for Objective 2 may be modified for faster execution to determine Objective 1 cumulative repair part failure profiles. In the Objective 1 determination of the failures expected in the scenario, we assume that all units have their authorized tanks in operationally ready condition at the beginning of each day. Furthermore, we assume that all repairable tanks in need of repair are repaired or replaced within 24 hours. In other words, the daily demand profile of repair parts required to keep the fleet of Abrams tanks in the given scenario in 100% operational readiness is determined. These statistics may be determined by executing the complete simulation model with an essentially infinite quantity of repair parts available for daily repairs of failed parts. However, this approach is unnecessarily time consuming when generating Objective 1 data.

Three modifications can be made to the model to take advantage of these assumptions while decreasing the model execution time from approximately 14 hours per 32 iterations to less than 1 hour. For a batch mode run of the 100 representative repair parts in this demonstration, these modifications roughly represent the difference between 100 hours or 59 days of computer execution time to generate identical data. First, all automatic data collection with the exception of the part failures experienced by tank units in the scenario are turned off. This may be accomplished using a search and replace editor to modify the simulation source code. Second, because all tank unit operational

readiness is assumed to be 100% at the start of each day in Objective 1, operational readiness rate calculations need not be performed during the simulation. The model is constructed to disable operational readiness calculations easily by changing the "count at start" attribute of the resource "OR Counter Part" from a value of one to a value of zero. By setting the "count at start" attribute to zero and never creating an instance of "OR Counter Part" during the simulation, the operational readiness algorithm is ignored. The window menu in which this is accomplished is shown in Figure G-7. Third, the number of tanks in a tank unit is effectively constant if each tank is operational at the beginning of each day. Therefore, the failure generating algorithms can be modified to use a constant for the number of tanks on each day. In this way, failures are always based on the authorized quantity of tanks in each unit, without the total overhead of moving repair parts through the repair parts system in the simulation. The only requirement is to have enough parts available so that the sum of inventory and initial number of tanks in each unit is greater than the number of failures assessed against a tank unit during the simulation. This restriction is required to accommodate a feature in

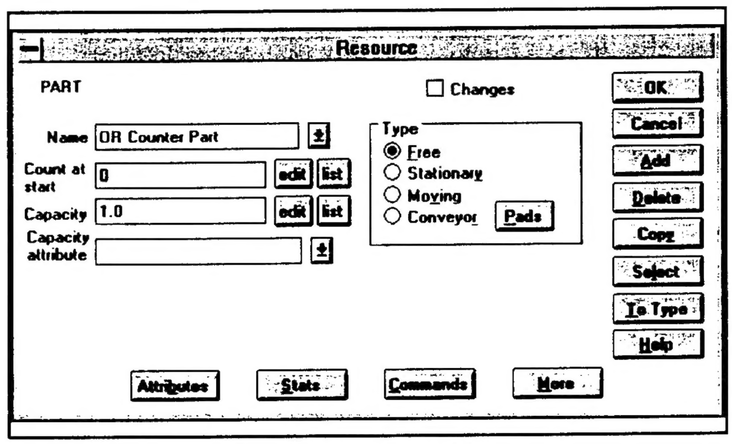


Figure G-7: OR Counter Part Menu

the repair part failure generation algorithms that ignores tank units having zero tanks operationally ready and thus unavailable to generate new demands. The two algorithms that assess failures in the simulation methodology are "zPart Failure - NEA" and "zPart Failure - SWA." A truncated command list, the name given executable programming code in SIMPROCESS, for "zPart Failure - NEA" is shown for comparison in Table G-1 and Table G-2. In the alternative simulation code for Objective 1 calculations, the variable "P1: Count," which contains the number of operationally available tanks at each unit location, is replaced by a constant equal to the number of tanks assigned to each tank unit in the scenario. Destroyed tanks continue to be removed from the inventory.

Identical failure profiles are generated regardless of which alternative is used to generate the Objective 1 data. The disadvantage of using two versions of the simulation program is far outweighed by the approximately 14:1 improvement in execution time realized. The full simulation model is required in all cases to evaluate the effectiveness of alternative policies for production capacity and inventory to provide required repair parts in a combat scenario.

Table G-1: Objective 1 Alternative Code for Part Failure Calculation

```
Command list              Yes
  do
    if cod[ atr[BN Mission Status(BN 30-1 NEA)] > 0.0
    and atr[Arrived in NEA(BN 30-1 NEA)] = 1.0 and
    atr[Part 1: Count(BN 30-1 NEA)] > 0.0 then ]
      if cod[ atr[BN Mission Status(BN 30-1 NEA)] = 4.0
      then ]
        release
          RESOURCE P1Fail BN 30-1 NEA
          Count: poi[cod[ 70.0*xpr[P1: NEA Fail
          Fac-Reserve]] ,10]
          Cond expression: 0
          Conditions: 0
      else
       if cod[ atr[BN Mission Status(BN 30-1 NEA)] =
       3.0 then ]
         release
           RESOURCE P1Fail BN 30-1 NEA
           Count: poi[cod[ 70.0 * xpr[P1: NEA Fail
           Fac-Reduced]],10]
           Cond expression: 0
           Conditions: 0
       else
        if cod[ atr[BN Mission Status(BN 30-1 NEA)] =
        2.0 then ]
          release
           RESOURCE P1Fail BN 30-1 NEA
           Count: poi[cod[ 70.0 * xpr[P1: NEA Fail
           Fac-Moderate]], 10]
           Cond expression: 0
           Conditions: 0
          else
           if cod[ atr[BN Mission Status(BN 30-1
           NEA)] = 1.0 then ]
             release
              RESOURCE P1Fail BN 30-1 NEA
              Count: poi[cod[ 70.0*xpr[P1: NEA
              Fail Fac-Intense]] ,10]
              Cond expression: 0
              Conditions: 0
           endif
        endif
      endif
    endif
endif
.
.
work 1.0
loop forever
```

Table G-2: Normal Simulation Model Code for Part Failure Calculations

```
Command list              Yes
  do
    if cod[ atr[BN Mission Status(BN 30-1 NEA)] > 0.0
    and atr[Arrived in NEA(BN 30-1 NEA)] = 1.0 and
    atr[Part 1: Count(BN 30-1 NEA)] > 0.0 then ]
      if cod[ atr[BN Mission Status(BN 30-1 NEA)] = 4.0
      then ]
        release
          RESOURCE P1Fail BN 30-1 NEA
          Count: poi[cod[ atr[Part 1: Count(BN 30-1
          NEA)]*xpr[P1: NEA Fail Fac-Reserve]],10]
          Cond expression: 0
          Conditions: 0
      else
       if cod[ atr[BN Mission Status(BN 30-1 NEA)] =
       3.0 then ]
         release
           RESOURCE P1Fail BN 30-1 NEA
           Count: poi[cod[ atr[Part 1: Count(BN 30-
           1 NEA)] * xpr[P1: NEA Fail
         Fac-Reduced]],10]
           Cond expression: 0
           Conditions: 0
       else
        if cod[ atr[BN Mission Status(BN 30-1 NEA)] =
        2.0 then ]
          release
           RESOURCE P1Fail BN 30-1 NEA
           Count: poi[cod[ atr[Part 1: Count(BN 30-
           1 NEA)] * xpr[P1: NEA Fail
           Fac-Moderate]], 10]
           Cond expression: 0
           Conditions: 0
          else
           if cod[ atr[BN Mission Status(BN 30-1
            NEA)] = 1.0 then ]
             release
              RESOURCE P1Fail BN 30-1 NEA
              Count: poi[cod[ atr[Part 1: Count(BN
              30-1 NEA)]*xpr[P1: NEA Fail
              Fac-Intense]] ,10]
              Cond expression: 0
              Conditions: 0
           endif
        endif
      endif
    endif
endif
.
.
Work 1.0
loop forever
```